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THE SCIENTIFIC MONTHLY

EDITED BY J. McKEEN CATTELL

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THE SCIENTIFIC MONTHLY

MARCH, 1924

THE ORIGIN, NATURE AND INFLUENCE OF RELATIVITY[1]

By Professor GEORGE D. BIRKHOFF

HARVARD UNIVERSITY

I. Euclid, Newton, Faraday and Einstein

A very simple and precise aspect of experience is that of the spatio-temporal relation between material objects. The underlying concepts of space and time have deeply influenced physical, astronomical, philosophical and even religious thought. A broad understanding of them appears to be indispensable for an adequate appreciation of the universe in which we live. The historical development of these concepts, culminating in the theory of relativity of Einstein, throws much light upon their nature. Perhaps the names of Euclid, Newton, Faraday and Einstein, more than any others, are representative of the various stages in the evolution which has taken place.

The significance of number, time and space must have been felt in the earliest period when man's mental power was comparable to that which he possesses to-day. Elementary facts about unity and multiplicity, succession in time, size and shape, are presented at every turn by experience. They have a curious inevitability and completeness, characteristic of mathematical truth, which was certainly perceived in this period. For example, the fact that there are two chief luminaries, the sun and moon, that they function in alternation, and that they resemble each other in size and shape must have stirred human interest even then. Doubtless the nascent elements of various fields of science were known to primitive man. The ability to handle material objects involved a perception of some principles of mechanics; experience in dealing with hot and cold bodies led to a familiarity with properties of heat; and the neces-

[1] Lowell lectures.

sary requirement of taking account of day and night, and of the seasons, brought about a grasp of a little elementary astronomy.

The systematization of the process of counting was the first great step towards that understanding of and control over nature which is characteristic of our day. At first there was only the process of counting by means of the fingers, stones or other objects. Then came the naming of the numbers, as one, two, three, etc., skill in reckoning with them, and their use in commercial pursuits, the measurement of land, and astronomy. Nearly two thousand years before our era the Egyptians were very competent in the use of number. The priesthood of that time had the leisure and interest for occupying themselves with scientific thought. A mathematical papyrus written by a scribe Ahmes, entitled "Directions for obtaining the knowledge of all dark things," witnesses to their arithmetic proficiency.

In their surveying, artistic designing and astronomy the Egyptians became adept in geometrical construction and must have

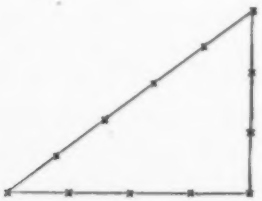

FIG. 1

been familiar with many truths of geometry. The right triangle with sides of three, four and five units was probably known to them and used in surveying. A floor in tiles with the pattern below indicated to the eye that the square on the longest side of a right triangle with two equal sides has an area precisely equal to the sum of

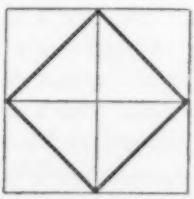

FIG. 2

the two areas of the squares on the equal sides. Moreover, practical urgency as well as merest curiosity led them to estimate with considerable accuracy the ratio of the distance around a circle to its distance through. The inscribed hexagon showed at once that the ratio exceeded three. Since that day long ago geometrical knowl-

edge has advanced very far and this ratio has been fully determined; it is exactly four fold as great as the number obtained when 1 is diminished by 1/3, then increased by 1/5, diminished by 1/7, and so on *ad infinitum*.

It may not be amiss to note in passing that not all elementary geometrical conundrums have yet been answered by professional mathematicians. Thus, map-makers have noted that apparently any imaginable map on the plane or sphere can be colored in only four colors in such wise that two countries with a common boundary

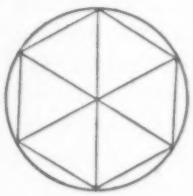

FIG. 3

line have different colors. Despite persistent efforts, the truth of this conjecture has not yet been established, although five colors are known to be enough. Of like intriguing simplicity is the question raised a few years ago by the Japanese mathematician Kakeya as to the least area within which a line of given length can be turned around in a plane. An area half as great as that of the circle with

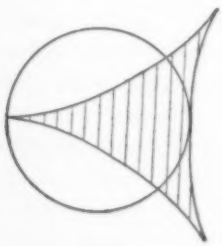

FIG. 4

this length for diameter will suffice. No one has as yet been able to prove that this is the least possible area.

Since all physical science depends upon the foundation of mathematical truth, of which the discovery has been hastened by intellectual curiosity, a high place can be granted such curiosity for its proved value to mankind.

No advance in the logical analysis of geometrical relations was achieved by the Egyptians. As soon as their empirical geometry had passed to Greece through the Greek geometer Thales about 600 B.C., it began to be transformed by Greek ability and interest

in abstract speculation. The great although obscure figure of Pythagoras has unusual importance for the early Greek period. The relation between the sides of a right triangle, illustrated in the triangle of sides three, four and five units, was probably discovered in its full generality by him. He found the two remaining regular solids of twelve and twenty sides, of which the Egyptians had known the other three. To him is attributed the determination of the relation between the length of a musical string and its pitch, exemplified in a simple way by the fact that if its length is halved, the note is raised exactly an octave. For Pythagoras these truths indicated a deep and mystical interdependence between number and nature. Number was taken by him to be at the root of everything, and its properties formed the foundation of his philosophy. Thus the regular solids represented elements in nature; the seven planets were held to give out musical notes proportionate to their distances from the sun, forming the music of the spheres.

Euclid, who lived a couple of centuries later, was the great systematizer of Greek geometry. His feeling for the purely logical side of geometry was uncanny in its accuracy, despite the fact that from the modern point of view the "Elements" are by no means free from blemishes. It was his achievement to have shown how all the known truths of geometry follow necessarily from a very small array of almost undeniable propositions called axioms and postulates. He was not primarily a discoverer of new geometric truths.

What interests us here is not so much the precise body of doctrine concerning points, straight lines, angles, circles, lengths, areas, etc., which he developed, as his point of view toward its application in the physical world.

In fact there are two alternative points of view towards geometric doctrine which can be held. One (that of Euclid) holds that we are dealing with a system of rigid bodies of fixed size and shape, of which material objects like tables, blackboards, rulers, the earth, etc., are fairly satisfactory embodiments. By handling these bodies and comparing them with one another, we arrive at the truths of geometry. For example, when it is affirmed that two points determine one and only one straight line, this may be taken to mean that if we fix upon two points A and B of a rigid body, then when the simple kind of rigid body called a straight line, and exemplified by any ruler, is placed upon the rigid body so as to contain the points A and B, the line will always be found to contain the same points of the rigid body, forming the straight line AB of the body.

It is entirely compatible with this interpretation that any rigid body can be indefinitely extended into a "space." Thus a man in

a moving railway train may estimate that a boulder directly opposite his window is 100 feet away and thus obtain its instantaneous position in the space attached to the train. The boulder also occupies a definite position in the space attached to the earth. Either of these spaces is in motion relative to the other.

The other point of view holds that there is a particular rigid body for which extension into a space is peculiarly proper, which space may then be called "absolute space"—a kind of omnipresent, penetrable, rigid body. Any material body fills a definite part of absolute space at any instant. With this interpretation the fact stated about straight lines means only that for a given pair of distinct points A and B of this space there is one and only one set of its points of the type called a straight line and containing these two points.

It was undoubtedly the second point of view that was generally held by the Greeks. Thus the point was a monad having position for the Pythagoreans. The conception of the point as that which is indivisible and has position was maintained also by Aristotle. Those who hold to the second point of view must contend with Aristotle that the principle of superposition has no place in geometry as a first principle, since two bodies may be superposed if and only if they occupy equal spaces.

On the contrary, Euclid himself, with that marvelous instinct for the essential which is characteristic of his work, defines the point as that which has no part, *i.e.*, as the indivisible rigid body, and does not require that it have position in some hypothetical absolute space. This fact and the use which he makes of superposition as a fundamental principle indicates that he preferred not to employ the concept of absolute space.

It is necessary to have the divergence clearly in mind.

Euclid saw that the science of geometry as applied in nature attaches no particular importance to any special reference body. Thus for him a point was merely a small identifiable rigid body. Rigid bodies were to be compared by superposition, and it did not make any difference just how the superposition was effected in any particular case. Consequently, to insist that any particular body defined an absolute space was unnecessary. It seems, then, that Euclid adopted a relativistic point of view toward space.

On the other hand Aristotle saw that in every-day experience a particular reference body, namely, the earth, played a preponderating rôle. It must have appeared to him that other rigid bodies were entirely unsuitable as reference bodies. Despite the fact that from a purely logical standpoint all rigid bodies stand on a parity in the geometry of Euclid, some such vague considerations, not essentially geometrical but rather mechanical in their nature, in-

clined Aristotle to maintain the concept of an absolute space attached to the earth.

The opinion to be presented here is that if some particular reference body has a superiority for the elucidation of nature, then it is desirable to signalize the fact by giving a special name to the space attached to the body. It is undesirable to pay any veneration to that space, since the fact is thereby obscured that, from the standpoint of geometry in itself, all rigid bodies are on an equal footing.

There is, then, a relativity present in the application of the geometry of Euclid to nature which allows us to start from any particular rigid body of reference, as defining a space of its own, and then to locate the position of other bodies at any time relative to that space. The relativity found here may be called *geometrical relativity*.

Before leaving the consideration of the Greek period, it is desirable to summarize the application of geometry in astronomical theory, for here the concept of time enters to join that of space, thus furnishing a very good vehicle for the statement and comprehension of the observed facts.

As might be expected, light was thought of by the ancients as instantaneous. Nearly two thousand years elapsed before it was discovered that light travels at the rate of nearly 200,000 miles a second. Consequently, events were correlated everywhere as happening when they were seen, this being done for events observed in the heavens as well as on the earth. Without any analysis of the notion of absolute time implicitly involved, a particular reference body and its absolute space was taken, to which the position of other bodies was then referred at any instant of absolute time. The explanation of astronomical phenomena was sought on the basis of this structure of space and time.

The application of geometry led very early to the recognition of the fact that the earth was a sphere. While traveling in Egypt Pythagoras became acquainted with this opinion. He seemed to have promulgated secretly the heliocentric theory, which gave the sun a central place. However, the dominant opinion of the Greek period held the earth to be absolutely at rest, *i.e.*, the venerated reference body. The great observing astronomers of near the beginning of our era, Hipparchus and Ptolemy, chose this theory. Ptolemy held any other theory to be ridiculous, despite the fact that he recognized the superior simplicity of the heliocentric theory for some purposes. While the geocentric theory, in which the earth defined the absolute space, had the advantage that observations were made in that space, it had the extreme disadvantage that the description of the motions of the sun, moon and planets became

very complicated. The concept of multiple epicyclic motion was invented to account for the facts in geocentric terms. In truth, to explain the motion of a planet on this basis, it was necessary to take account successively of rotations in three distinct spaces.

In the sixteenth century of our era, Copernicus selected the sun (taken as not rotating in the frame of the fixed stars) as defining the reference space. The theory of Copernicus found only slow acceptance. From our point of view the real significance of his theory is that the explanation of the astronomical facts is in this way made very much more simple. No doubt the Copernican theory would have been accepted at once by Euclid, for none would be more ready than he to grant that the new theory was accommodated to pure geometry fully as well as the Ptolemaic theory.

In the seventeenth century Kepler and others, under the stimulating simplicity introduced by the Copernican ideas, were able to understand and follow the motions of the moon and planets far more accurately than had been done before. There arose the belief that the same gravitational force which pulled terrestrial bodies to the earth was also operative between bodies at great distances apart, and controlled the solar system. However, the mathematical means for investigating the truth of this conjecture had not yet been invented.

The discovery of analytic geometry by Descartes in the first half of the seventeenth century was a first necessary step in this direction; the Pythagorean vision that all was number was thereby justified in the field of geometry. It is the achievement of Newton to have invented the infinitesimal calculus, which deals with varying quantities, and to have applied it to the problems of the solar system. A brilliant result was his law of universal gravitation.

The dogmatic adherence of Newton to the doctrines of absolute space and time is sufficiently apparent from the first scholium of his "Principia." A translation of a few characteristic passages will show with what seriousness he subscribed to these doctrines:

> I. Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration; relative, apparent and common time is some sensible and external (whether accurate or unequable) measure of duration by means of motion. . . .
>
> II. Absolute space, in its own nature, without regard to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute space. . . .
>
> III. Place is a part of space which a body takes up, and is according to the space, either absolute or relative.
>
> IV. Absolute motion is the translation of a body from one absolute place into another; and relative motion, the translation from one relative place into another.

Of course Newton endeavored to justify his unqualified adher-

ence to these doctrines. In fairness to him it must be said that he succeeded partially in doing so in the following manner. Imagine a dumb-bell tossed into empty space at such a distance from any other bodies that gravitational forces need not be considered. On the basis of Newton's laws of motion, it follows that there will be a tendency of the weighted ends to separate if there is any rotation, whereas if there is no such rotation, there will be no such tendency. Thus, "absolute rotation" can be detected by means of the slight elongation of the bar joining the weights. Hence, there are mechanical methods for ascertaining absolute rotation. Direct experiment indicates that such rotation is merely rotation with reference to the so-called fixed stars.

The case of motion in a straight line with unvarying velocity stands on an entirely different basis in Newton's theory. There is given no principle by which such uniform rectilinear motion of an undisturbed body in empty space can be ascertained, and it is inherent in his entire system of thought that this is so. Newton himself realized the situation more or less vaguely for he says in the same scholium: "It is indeed a matter of great difficulty to discover, and effectively to distinguish, the true motions of particular bodies from the apparent; because the parts of that immovable space in which those motions are performed, do by no means come under the observation of our senses. Yet the thing is not altogether desperate. . . ."

For example, on the basis of Newton's theory the sun is an undisturbed body, at least if the minor disturbing gravitational forces of the planets and other heavenly bodies are ignored. According to his theory, it may be either at rest in his absolute space, or describing a straight line in that space with constant velocity. His formulation of mechanical principles is such, however, that if the motion of all the heavenly bodies be computed on the hypothesis that the sun is at rest, *i.e.*, using the space attached to the sun, the result predicted will be exactly the same as if the space of any other star than the sun is taken to be at rest.

The advance of the Newtonian over the Euclidean point of view can be stated in dispassionate terms as follows. Newton accepts the truths of geometry, according to which there are as many spaces as there are real or ideal rigid bodies, and yet he notes that some spaces are more suitable than others for describing natural phenomena, namely, the spaces attached to rigid bodies moving freely in empty space and in such wise as to be subject to no tendency of their parts to separate. It is only with respect to such a space that his first law of motion holds: "Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon."

His doctrine of absolute space insists unnecessarily that one such space is supremely important, and accordingly to be termed "absolute." But the fact is that all his laws of motion are expressed in identically the same way whatever such space is employed. An illustration of the truth of this fact is afforded by the behavior of a ball in the space of an elevator which is descending at a constant velocity. It will be found that the ball falls in this space exactly as though the elevator were at rest.

Newton's corpuscular theory of light and his law of gravitation have this characteristic property of relativity.

If the space of a rotating body is selected, any freely moving body describes a complicated spiraliform curve in it. Thus the choice of Newton of reference spaces attached to a special type of freely moving body, namely, any one not in absolute rotation, is justified by the test of simplicity. There is no justification for the selection of a special one of the possible reference bodies of this type as against all others.

Consequently, on the basis of the Newtonian theory a *mechanical relativity* holds sway which is not as inclusive as the geometrical relativity signalized earlier, but which fails nevertheless to distinguish between the spaces of various bodies in uniform translational motion relative to one another.

The success of the heliocentric theory turns upon the fact that the sun is far more nearly an undisturbed body in such uniform motion than the earth, moon, or planets. But the space used can not rotate with the sun and so is of the Copernican type; otherwise the stars would travel in circular orbits in the space, contrary to the first law of motion. The real motive for the use of the heliocentric system is now reduced to its proper basis, namely, that with this type of reference body the motions observed can be described with maximum simplicity.

Undoubtedly Aristotle had a vague feeling for the fact that when mechanical ideas are admitted there is less relativity allowable than when only purely geometric considerations are taken into account. This is especially apparent when he classifies motions as being according to nature and contrary to nature. However, he made no analysis of the reasons for his choice of the earth as a uniquely determined reference body, and indeed could not have been expected to do so.

The full validation of the concepts of absolute space and time seemed to be at hand when the rôle of electricity and magnetism in nature began to be discovered. These phenomena were the latest to impress the attention of physicists, so that even magnetism was scarcely mentioned by Newton.

The name of Faraday stands foremost among those who have

investigated the facts concerned. To him is due the first complete statement of the interrelation between electrical and magnetic phenomena. He was the only one of the four men towards whom we are directing especial attention who was not a working mathematician. He lamented his lack greatly. It required his mathematical interpreter Maxwell to give Faraday's concretely expressed "lines of force" an exact and adequate statement. As Maxwell says of Faraday in the preface of his "Electricity and Magnetism":

> Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centers of force attracting at a distance: Faraday saw a medium where they saw nothing but distance: Faraday sought the seat of the phenomena in real actions going on in the medium, they were satisfied that they had found it in a power of action at a distance impressed on the electric fluids.

When Maxwell had succeeded in giving the concepts of Faraday satisfactory mathematical formulation, he found that it followed also that the electromagnetic wave, such as is sent out from any wireless station to-day, travels of necessity with one and the same velocity under all circumstances in empty space, and that this velocity is given as the ratio of two well-known units in electricity and magnetism. Of course, the velocity is relative to the medium imagined by Faraday, called the ether and conceived as a particular one of the Newtonian spaces, namely, the one which Newton signalized as "absolute." Maxwell found that this calculated velocity was the same as the known velocity of light. Thence he derived the epoch-making conclusion that the light wave is electromagnetic, *i.e.*, the same in type as the wireless wave. All subsequent investigations have verified the truth of this conjecture and also the adequacy of his mathematical equations for expressing the facts of light and electromagnetism. Faraday had conjectured a relation between light and electricity. Maxwell demonstrated it in all detail.

At last the absolute space of the Newtonian philosophy, which had provoked numerous questionings since it seemed without substance, began to have definite properties. At last there appeared to be a basis of distinction between the various mechanically equivalent spaces of Newton by means of the electromagnetic ether. Thus in turn the geometrical concepts of Euclid, the mechanical concepts of Newton and the concepts of electric and magnetic interaction of Faraday narrowed the possibilities down so that all spatial relativity was apparently excluded. There were many who conceived that the main laws of the physical world had been formulated, and that nothing further remained than to ascertain the precise way in which atomic matter and electricity were joined together in the atom.

As in any genuine theory this view of nature was left open to verification. It became possible to determine absolute motion through the ether by experiment, and so discover absolute space. The fundamental method suggested for this ultimate quest can be explained as follows: If a man swims up-stream a given distance and back, he will find that it takes him more time to do so than if the water is at rest. This is particularly apparent in case he makes only slight headway against the stream. It is assumed that his velocity through the water is the same in both cases. Now a rigid body in motion through the ether may be compared to the banks of the stream, the ether to the stream which is moving past the body, and a beam of light which is flashed from a point of the rigid body to a second point at a given distance from the first and reflected back again, to the swimmer. It ought to take more time for the beam to travel back and forth along a bar in uniform motion in the ether than if the bar is at rest.

Owing to the variable character of the earth's motion, it was found possible to devise apparatus by which this increase of time should be revealed by a shift in position of certain interference fringes. As carefully tested in this way by Michelson and Morley in 1887, the earth showed not the slightest trace of motion relative to the ether. The attempt to explain the negative result by means of the hypothesis of a "drift" of the ether with the earth was meaningless, since the ether was by hypothesis a particular one of the Newtonian spaces, and the equations of Maxwell called for one and the same velocity of propagation of light in empty space of this sort under all circumstances. Such a suggestion of ether drift must remain incomprehensible until some modification of the foundations of physical theory is made. No one has proposed a definite and consistent modification of this kind.

A variety of subsequent experiments confirmed the general conclusion that the earth was entirely indifferent to motion relative to the ether. Nature unexpectedly refused to yield up the long held secret of an absolute space at the very moment when all were of the opinion that it was to be wrested from her.

The perplexity into which physicists were thrown by the situation was much more embarrassing than appeared at first sight. Absolute space was intangible, and it began to appear that absolute time was not much less so. If the synchronizing of clocks at different places on the earth's surface is to be effected accurately, a method of light signaling must naturally be employed. Without a knowledge of the velocity of the earth in the ether it is not possible to allow exactly for the time required by the signaling process. In fact the natural way of synchronizing such clocks appeared to be

to assume the earth at rest in the ether, because of the absence of any effect; and this was out of the question inasmuch as then the timing would not be absolute but only relative to the earth.

The notion of absolute time has been taken without the slightest analysis in the historical sketch attempted above. It is necessary now to begin to consider ideas of time as well as of space, and hence it must be pointed out what a sweeping hypothesis is involved in the notion of absolute time. Suppose that I snap my fingers. Events happen throughout the universe which I propose to bundle together as having happened at the same instant. The method which I use to determine the events happening at the instant must be physically unique and not arbitrary in the least degree. If the physical means adopted of finding these events has any uncertainty in it, the measurement of distances will share in the uncertainty, since the position of a body at one instant of time will be compared with the position of a second body at a different instant.

At first thought it might occur to me to correlate events as happening when I see them, for this is the method of ordinary experience. If I did that, however, I would consider a change in the light from a distant star to take place when it becomes visible through the telescope, contrary to all astronomical procedure.

For these reasons it is clear that the notion of absolute time involves a definite hypothesis concerning the physical structure of the universe.

A variety of physicists and mathematicians, among whom Fitzgerald, Lorentz and Henri Poincaré are particularly to be mentioned, speculated upon the difficulty, without avoiding the unnecessary hypothesis.

In 1904 Lorentz arrived at a kind of solution of the problem, which it is most instructive to consider. He assumed that the very circumstance of motion relative to the ether caused a moving body to contract in the direction of its motion by a part of its length (a few inches in the case of the earth), and a moving clock to slow down in the same ratio, precisely so as to account for the result of the Michelson-Morley experiment. It was as though the swimmer alluded to were required to go up-stream a shorter distance and the clock was running a little slowly, so that he was considered to take exactly the same time in both cases. This hypothesis accounted for all the experimental results which offered difficulty.

The hypothesis of contraction presents two curious features. The first one is that it is incompatible with the ordinary concept of the rigid body as of fixed dimensions under all conditions. Henceforth only rigid bodies at rest are held to be of fixed dimensions.

The second feature is even more significant and deserves partic-

ular attention. It appears that if experiments are carried out on the body in uniform motion as if it is at rest, so that its length is held to be the same as when at rest, then the laws observed to hold are identically the same as if the body is truly at rest in absolute space. On account of the slowing down of clocks and the contraction of lengths as stated, it is at least clear that the velocity of light will appear to be the same for the reference system in motion as for the reference system at rest. The same result holds throughout.

This situation indicates nothing else than that it is experimentally impossible to distinguish between absolute rest and uniform motion in a straight line. Relativity, after being denied a position in the theory by general consent, is entering upon the stage without that consent. The relativity is, however, of a new type because of the fact that the time as well as the space of the reference body in motion is distinct from that of the body at rest. In his theory Lorentz used the term *local time* to describe the time relative to the moving body.

If, despite the fact just referred to, according to which the various reference systems are physically indistinguishable, one deliberately prefers to single out a special reference system and call it "absolute," there can be no objection, any more than there can be to any arbitrary harmless act of the will. However, it is a privilege without physical significance.

Einstein was the first to perceive the true nature of the situation which was giving difficulty, and formulated the appropriate principle of relativity in 1905. The great stroke of critical insight on his part was to be able and willing to abandon the notion of absolute simultaneity which had never been questioned before. It has been stated that the notion of absolute simultaneity implies a significant correlation of events. If the velocity of light were infinite, the correlation would be immediate. It is finite, however, and the experimental facts indicate that the space and time of any undisturbed non-rotating body, *dealt with as though it is at rest*, have exactly the same physical properties as the space and time of other such body similarly dealt with. Why not take as equally valid all these spaces and times, and then attempt to correlate them without employing the hypothesis of absolute simultaneity? The new kind of relativity obtained, in which all such spaces and times appear on an equal footing, and not only mechanical properties of matter but also electromagnetic properties are taken into account, may be termed *optical relativity*. This relativity is spatio-temporal in character.

It is possible now to review the general course of the development of the concept of space and time.

At the outset events were taken to happen as seen, and the notion of absolute simultaneity was accepted as self-evident truth, which was natural under the circumstances.

The first treatment of space turned on the Euclidean analysis of the rigid body and of the attached space which it defines. Any body was equally suitable as reference body, so that (for example) it was legitimate to use either the space of the earth or the space of the sun as the reference space. This was the geometrical relativity of Euclid.

A more careful analysis of bodies, which took account of their mechanical properties, although using the concept of the space attached to a reference body at any instant, made it possible for Newton to go a step further and eliminate rotational relativity. Thus, the sun in the frame of the fixed stars was the superior body of reference in the solar system because it was nearly in the state of undisturbed motion without rotation, which considerations of convenience required of the reference body. Any other star than the sun would serve as well as the sun in yielding a space of reference of the best Newtonian type. Herein lay the mechanical relativity of Newton.

Then came the last step in advance, made possible only by the realization that, just because light travels at a finite velocity, absolute simultaneity is meaningless unless defined by a physical process. If the Newtonian relativity is slightly modified so as to admit the relativity of time, as well as of space, to any reference body in an undisturbed non-rotating state, a more homogeneous treatment of the physical universe is obtained, from the very nature of which it becomes impossible to choose any particular such space and time as possessing a superior validity. Such is the optical relativity of Einstein.

Thus, after space and absolute time have been used in the account of nature for nearly two thousand years, it has been found necessary to replace these concepts by a union of the two, called space-time. Under ordinary circumstances the old and new theories differ inappreciably in their measurable consequences, and yet only the new theory will be found to explain certain phenomena in a satisfactory manner.

The one outstanding fact which must be granted before the new theory of relativity can be properly understood is that the notion of absolute simultaneity is not a self-evident truth, but implies a significant physical correlation of events.

MODERN CONCEPTIONS OF EARTH HISTORY

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GEOLOGY is the history of the earth. I have it on student authority that most history is dry, and ancient history especially is dry. The more ancient, the more dry! And neither Tut-ankh-amen nor Tiglath-Pilesar has anything on Mother Earth, when it comes to ancient history. However, it has lately been discovered that the more history is "boiled down," the juicier it becomes. Wells and Van Loon, working in separate laboratories, have each discovered the process by which continued boiling will eliminate the cellulose and mineral matter of history, and leave a rich, digestible juice. I propose here to use their method, though on a different broth and, submitting the results to a different group of judges, to learn, probably, that I am no Wells or Van Loon.

The history of the earth is read from the rocks of the crust (the lithosphere) and the salts of the ocean (the hydrosphere). The hieroglyphics which we interpret are:

(1) The original character of the rock, whether igneous or sedimentary;
(2) The original structure in the rocks, produced at the time they were cooled, or were deposited as sediment;
(3) The secondary structures, the result of subsequent molar and molecular changes; and
(4) The fossils embedded in the sedimentary rocks, our sole reliance for correlation and dating.

To decipher the meaning of the rock record, almost every phase of modern science must be brought to the task. So varied are the special trainings necessary that it may be said that there are no geologists to-day. There are mineralogists and petrologists; stratigraphers and sedimentationists; paleontologists, paleobotanists and paleogeographers; vulcanologists and seismologists; economic geologists and structural geologists; geochemists; geophysicists and geodesists; glacialists and physiographers; and, finally, embryo geologists and pseudo-geologists, all contributing their mite to the erection of the structure which we call the history of the earth.

A PHILOSOPHY OF GEOLOGY

When men first began to recognize that the rocks of the earth held a record of past changes, their ideas were strongly colored with preconceived notions, derived from various philosophies and re-

ligions. Catastrophes, like the great inundation in which Admiral Noah figured so largely, and like the big fire in the tough old towns of Sodom and Gomorrah, with the associated record-breaking petrifaction of Lot's wife, were the ruling ideas. River valleys were thought to be the erosive result of great waves which swept inland from terribly enraged oceans, or the consequences of tremendous shattering earthquakes of the distant past; the glacial deposits of northern North America and Europe were similarly the record of debacles of horrifying proportions, when whole oceans apparently arose in their wrath and charged across inoffending lands, leaving death, drift and destruction in their wake! The element of vast duration was not in their philosophy. The whole story covered but a few thousands of years.

Later there arose a school of English observers of nature, whose fundamental tenet was dubbed "Uniformitarianism." They argued that the cumulative result of river erosion had formed the valleys which the streams now occupy, that volcanic cones had been slowly built up of the ejectamenta of many eruptions instead of having been heaved up abruptly, that the whole history of the earth, as recorded in the rocks, was to be interpreted in terms of geological changes going on under our very eyes and extended through eons of time. "The present is the key to the past," they said.

Though uniformitarianism was much nearer the truth than the earlier cataclysmy, it is not considered to-day to be the whole truth. I want to raise the question "Is there a philosophy of geology?" "Is there a general scheme?" "A unity?" The answers I shall suggest will be founded on the geological doctrines prevailing to-day, especially in the American school. In the interest of brevity and that desired juiciness, I may be permitted to neglect certain objections and exceptions. At the worst, I shall tell only a few little white lies. Geologists never tell "whoppers"—about geology.

Sources of Energy

Changes great and revolutionary have occurred in the history of the earth. What are the sources of energy which could have produced these changes? Without pursuing the analysis very far—only geophysicists know everything about this subject, and I am no geophysicist—let us note that all sources of energy fall into two groups: (1) Telluric sources—resident within the body of the earth, and (2) extra-terrestrial sources—chiefly our sun. Both groups have worked through all recorded history on the surface of the earth where we read the record.

Geological Processes

Geological changes are, and have been, of three different categories: gradation, diastrophism and vulcanism. Gradation is the sum of all changes which tend to wear down the higher parts of the lithosphere and to build up, or fill up, the lower parts. Diastrophism embraces all movements in the solid lithosphere. Vulcanism is the movement of molten material in and on the surface of the lithosphere.

Gradation embraces the degradational processes of weathering, erosion and transportation to lower places, and the aggradational changes which are a necessary consequence. A circulating atmosphere and hydrosphere are essential. Witness the topography of the moon, where there is neither atmosphere nor hydrosphere—it is apparently unaffected by gradational changes. The source of energy for gradational changes is solar.

Continued without interruption of the process, wind and running water would eventually inevitably reduce the lands of our sphere to low, featureless plains, which the physiographer terms "peneplains." Uninterrupted marginal attack on these lands by the waves of the sea would eventually inevitably reduce the continental areas to shoal water, the depth determined by the lower limit of the ability of waves to erode (wave-base).

These are not purely theoretical conclusions. There do exist to-day large land areas of low relief, essentially planes, beneath which are rocks of very different characters, structures and degrees of resistance to erosion. In only one way could such planes be formed in such situations. They have been scrubbed down by erosion, and are the ultimate stage in a topographic cycle, or cycle of erosion. They are peneplains.

However, not all peneplains now lie in the situation where they were formed. Many are elevated high above the present base-level of erosion in their region, and are being destroyed in a newly inaugurated cycle of erosion. Many mountain ranges carry on their summits the remnants of ancient peneplains. The Appalachians constitute our classic American example. The ancient peneplain is identifiable by an accordance of summit levels over a mass of disordered stratified and igneous rocks, now deeply eroded into a second cycle of mountains.

In contrast with such situations, many peneplains lie buried in the accumulated sediments of the ages. They were submerged, instead of being elevated, after their formation. If we can date the sediment resting on the old land surface, we can place a minimum estimate on the age of the peneplain; that is, on the time since it was completed.

Suffice it to say here that the geological record contains incontrovertible evidence that peneplanation has occurred repeatedly; that the time necessary for its consummation is but a small fraction of the total duration recorded. It is obvious, therefore, that gradation is fully competent to destroy all lands, and that the experiment has been set up for a sufficient time to permit the action to occur. Yet here are the lands of the globe, covering one fourth of the total area, averaging half a mile in altitude, and attaining summits five and a half miles above the sea. If I may be allowed a figure—the lands, like the giant Antaeus, though repeatedly downed by the Hercules "Gradation," have arisen greater than ever! Why are there lands to-day?

Geological Periods

Let us leave this question unanswered for a while and consider another matter. When men, after recognition of the chronologic value of fossils, began to decipher geological history, they used the term "systems" to denominate those strata which contained similar fossil faunas. In general, "systems" turned out to be fairly definite units the world over, and the term "period" came into use to denote the time during which a system was deposited. Each system was made up largely of a series of marine deposits on the continental surfaces. Some of these are so widespread that we know that nearly 75 per cent. of what is now North America was at times submerged. The "system," which is the record of a "period," is the record of a marine transgression on the continent.

Another fact of great significance is that, in general, each system lies on the eroded surface of the subjacent, older one. It is unconformable, in geological jargon, on the older system. From what we have already said, it is clear that these breaks, these unconformities, are records of times when the continent was a land surface. The alternation of systems of marine strata with unconformities is clearly a record of alternating submergences and emergences.

Another noteworthy point is that the strata of the older system in many cases were folded and faulted before the erosion occurred. The record, therefore, in the case of two systems thus related is:

(1) Submergence of a continental surface and deposition of the first system of marine strata;
(2) Emergence of the continental surface;
(3) Deformation, perhaps contemporaneous with (2);
(4) Erosion, perhaps to peneplanation;
(5) Submergence, and consequently deposition of the second system unconformably on the deformed and eroded first system.

Once the shallow seas are spread over a large portion of a continent why should not this condition remain in perpetuity? The answer is—diastrophism! Differential movement in the litho-

sphere! And in this movement, the continent behaved essentially as a unit. Either it was uplifted so that the shallow seas were drained off, or it held its own while the ocean basins were deepened, the result being the same in either case. The lands are renewed because of diastrophism, the shallow epicontinental seas are withdrawn and the sedimentary record interrupted because of diastrophism. Erosion is initiated because of diastrophism.

There remains the question of submergence of the eroded lands. Why has the sea spread so widely after a time of uplift and erosion? The prevailing interpretation for this characteristic feature of the rhythm of earth history is that erosion of the newly uplifted continents produces a quantity of waste which goes overboard into the bounding ocean basins. This displaces water sufficient to cause the submergence. If the present continents were to be eroded to sea level, and the débris to be dumped into the margining oceans, the ocean surface would be raised 650 feet. Such a rise to-day would flood the Gulf of Mexico northward over into the Great Lakes region and there join with another flood up the St. Lawrence embayment, all this without any lowering due to the erosion which we specify should occur to cause it.

During the slow progress of an erosion cycle and the consequent rise of sea level, the encroachment of the sea would be very gradual, and would progress from the periphery toward the interior of the continent. Formations deposited early in any period should be limited in area and near the margins of the continent. Deposits of the middle and later part of a period should have a maximum extent and should be spread from the continental margins to the interior. Now, this is what we find, repeated over and over, in the geological record. The marine invasion extends gradually to its maximum, and, of all areas submerged, the continental interiors are the last to become inundated.

The physical history of a typical geological period, summarized, would be as follows:

A (1) A long time (perhaps several million years) of sedimentation on the continents.
(2) The shallow seas spread more and more widely, reducing the land area to half or less of the total continent.
(3) The surviving lands become greatly lowered by erosion.
B (4) Diastrophism awakens in time to prevent the complete destruction of the lands. The seas are withdrawn into the deep ocean basins, the lands emerge.
(5) Deformation of the new sediments and perhaps mountain-building occurs.
(6) Most of the continent becomes land.

And the period is closed!

The succession of events in a geological period, and the rhythmic succession of the periods themselves, is due to the interaction of the two great sources of energy already named. The part played by gradation is due to extra-terrestrial energy, that played by diastrophism to telluric energy. Diastrophic changes set the stage for the gradational part of the play. Were diastrophism to cease, a complete water-cover for the globe would result and there would be no further history.

Diastrophism Periodic

The rhythm of earth history depends, therefore, on telluric sources of energy and the recurrence of diastrophism. A fundamental question must now be considered—"Why should these great throes of the earth be periodic?" Even more fundamental—"Why should they occur at all?" Studies of the structure of mountain ranges the world over have shown that their making has consisted essentially in a tucking up of the girth of our mother earth. That estimable matron is getting smaller and more wrinkled as she gets older. In the folding and thrusting which piled up the Alps, 75 miles, perhaps much more, of circumference of earth was eliminated at right angles to the trend of this range. In the making of the Appalachians, a shortening of 46 miles was accomplished. In a single great thrust in the Canadian Rockies, an overriding of 15 miles or more is measured.

Lateral (horizontal) compression clearly is the direct cause of such shortenings. In the absence of any evidence to show that this was accompanied by an equivalent spreading elsewhere, and the apparent mechanical impossibility of such a change, the interpretation is made that this is true circumferential shortening, due to radial shortening or shrinking.

We do not yet have an answer to the question, "Why has the body of the earth shrunken during the geological past?" Or rather, I ought to say, we have dozens of answers! It amounts to the same thing either way. But we do know the procedure and the results it has produced: (1) Distributed radially, this shrinkage has drawn down the ocean basins more than the continental platforms and thus has produced those great relief features of the lithosphere; (2) resolved into horizontal components, it has caused great thrusting, apparently from ocean basin tracts against continental platform tracts, and consequent marginal mountain folding; and (3) its distribution in time has been periodic.

What is the nature and condition of matter in the interior of the earth? About this subject we know very little. Its density is high, for surface rock averages 2.6 specific gravity, and the earth as a whole is 5.6. Its rigidity is high, for it has a body tide of elastic

character, and it transmits earthquake shocks with a velocity higher than they would have in tool steel. Though the density is high, anomalies of gravity show that it is not equally distributed. The value of gravity over the ocean basins is 3 per cent. greater than over the continental platforms.

Hypothesis of Earth Mechanics

Based on facts already presented, there has been formulated a hypothesis for the general mechanics of earth shrinkage during geological history. This hypothesis, with many other ideas I am suggesting to-night, we owe to the Nestor of American geology, Professor Emeritus T. C. Chamberlin, of the University of Chicago. Let us review the fundamental facts on which the hypothesis is founded. They are as follows:

(1) Earth's interior is rigid, not molten, as the old ideas had it.
(2) Material beneath ocean basins is heavier than beneath continental platforms.
(3) Diastrophism, on a great scale, has been periodic in the history of the earth.
(4) Continental platforms and ocean basins have been unit tracts during history of the earth.
(5) Major adjustments have occurred between continental platforms and ocean basins.

The hypothesis is as follows:

(1) Increasing density of a heterogeneously aggregated but segmented earth body, due perhaps in part to loss of heat, but much more largely to physical and chemical reaggregation under the enormous pressures in the earth's interior;
(2) Resistance in the exterior portions of the earth's body to yielding *pari passu* with the increasing density of the deep interior;
(3) Consequent accumulation of gravitative stresses, the time of such accumulation measured in millions of years;
(4) Eventual passage of stress into strain—yielding—the heavier ocean basin segments settling more than the lighter continental platform segments —crowding of segments and making of marginal mountain ranges by the horizontal thrusts;—a diastrophic revolution!
(5) The stresses eased, quiescence occurs and gradation now begins a new cycle of erosion, in turn to cause a new flooding over on the continents.

Faunas of the Geological Systems

Let us now go back to a subject earlier introduced, but not elucidated—the contrasted faunas of the different systems of rocks. The changes in faunas are so great from system to system that in some cases the doctrine was once entertained that there had been complete annihilation and a new creation of forms of life after the break. Though we now know that some invertebrate forms lived

through several geological periods, in general there are striking faunal changes from period to period.

Consider the situation of the widespread shallow-water marine faunas at the time diastrophism awakens. These shallow seas are drained, and the forms must migrate or perish. The migration itself means extinction for many kinds which have specialized to that fatal extent that plasticity has been lost. The depth, the temperature, the clearness or turbidity, the kind of bottom, the kind of food, all must change, and if the ability of adaptation has been lost, all is lost! Witness the transition from the Paleozoic to the Mesozoic era. Of 10,000 species, but 300 survived. Ninety-seven per cent. became extinct. Only the stress of the physical changes can account for such a faunal change among the marine invertebrates. Thus the diastrophism, springing from interior changes in the earth, and determining the areas of land and water, the topography of the lands and the areas of sedimentation and erosion, determines also great and rapid changes in the forms of life.

The paleontologist, therefore, conceives of two speeds in the evolutionary development of life. One of these is witnessed while physical conditions remain much the same. The other occurs when diastrophic disturbances alter the even tenor of the faunal ways, and is considerably more rapid. At such times appear the characters of major importance—such as distinguish classes—with comparative rapidity.

Climate

A very interesting feature of earth history is the record of revolutionary changes in climate. Of the most recent of these changes, you are all aware. You know that the Great Lakes region, and the northern part of the Ohio, Mississippi and Missouri drainage areas is smeared with a deposit of clay, sand and gravel; unstratified, heterogeneously intermingled. You know that this deposit rests on strikingly planed, grooved and striated surfaces of the bedrock, and that many of the contained boulders are themselves planed and striated. You know that these phenomena are accepted as proof that the region was covered by a continental ice sheet, similar to those of Greenland and Antarctica to-day. Yet this region enjoys a much milder climate now than it did a few tens of thousands of years ago, and with the aid of a certain newspaper scientist, day by day in every way it is getting milder and milder.

If we go below the glacial drift at Chicago, we find the Niagara limestone containing many splendid fossil coral reefs. Aside from the record of an early marine submergence of the region, this constitutes a record of a sub-tropical climate. Reef-building corals to-day can not live in water which cools below 68° F.

The fauna of the Niagara limestone is known about Hudson Bay where there are very similar reefs, and even in Greenland, less than 9° from the North Pole. Not alone was the climate sub-tropical, if we may trust the evidence of the reef-building corals, but it also was non-zonal.

Thus the geological record at Chicago, taken as an example, tells of great climatic changes. But before taking up this subject of the geological oscillations of climate, let us note that probably the most remarkable thing about the history of climate is its uniformity. Throughout uncounted millions of years, the climate of the earth as a whole has remained above 0° C. and below about 45° C., the approximate limits under which living forms may survive. The cause of such uniformity lies primarily in the sun, and the problem is essentially astronomic. Here, however, the geologist humbly tells the astronomer some things about the life of the sun, things the astronomer ought to know. Time was when the astronomer condescendingly told the geologist how much time he could have for the development of life, and the physicist backed him up. Now the physicist is on our side.

The variability of climate, about which I wish to speak for a few minutes, is within these limits of 0° and 45°. There are climatic variations of many orders of magnitude and of time values. Alternations, cycles, pulsations, precessions, fluctuations and oscillations are recognized. I shall discuss only the great oscillations which are intimately related to the geologic periods. The earlier idea of climatic change was a simple one in perfect harmony with the Laplacian or nebular hypothesis, which postulated a molten condition of the early earth. The climate of that earth was *hot*. It was hotter than a July day in Chicago—*i.e.*, hotter than Gehenna! Gradually, with radiation of heat into space, the temperature lowered and finally the first crust of the earth appeared. In other words—hell froze over! The solidified crust has grown ever thicker and thicker, and the climate ever cooler and cooler up to the present. Final crystallization of the remaining molten material, including that liquid mineral water, is just around the corner.

This cheerful view has long since been in the discard. The record of the rocks shows that it can not be true. On the surface of the oldest granites, the primitive crust of the older interpretation, and virtually at the bottom of the whole series of sedimentary deposits in North America, has been found record of glaciation. This occurred when, according to the older view, the granitic crust was still sizzling hot, and the atmosphere contained the present oceans.

It is essentially correct to say that the stratigraphic history of the earth begins with glaciation, and ends with glaciation. But this

isn't all! In the billion years, more or less, of this history, there have been several glaciations (though during most of this billion years, the earth has enjoyed mild, equable, non-zonal climates). One of these glaciations was even more remarkable in its extent than either the earliest or the latest. It saw glacial ice at sea level in peninsular India, lat. 19° N., moving northward, away from the equator.

And, contemporaneous with glaciation, has occurred aridity, the record similarly indubitable. Glaciation and aridity may not seem, at first glance, to be well-mated partners. But consider the earth to-day! It has great areas covered with glacial ice (Antarctica alone has four million square miles of glacial ice, an area equal to half of North America) and it has still greater arid areas. The favoring conditions for both are extensive land areas. Aridity and glaciation are extreme cases of the continental type of climate, as contrasted with the oceanic type.

If the earth to-day, with widespread elevated lands and restricted oceanic spread, is arid in places and glaciated in others, we expect that similarly in the past, widely emergent continents should have been accompanied by glacial and arid climates. The converse of this: the times of widespread seas and low and limited lands, should have witnessed equable climates.

When we examine the geological record, we find this to be the case. Glaciation and aridity have occurred during and immediately after the great diastrophic revolutions. The equable climates have prevailed during the times of diastrophic quiet. The climatic variations swing in unison with the gradational and diastrophic changes already outlined.

That there is a causal relation is clear. It can not be coincidence. But are the varying extents of land and water adequate as direct causes? Is interruption in oceanic circulation from large land areas and constricted oceans, and interruptions in atmospheric circulations from lofty mountain ranges and plateaus sufficient to produce these differences? Almost no one thinks so.

Tyndall long since suggested that variation in quantity of carbon dioxide in the atmosphere might affect climate. This germ of an idea has been developed by Professor Chamberlin into a closely reasoned, strongly buttressed hypothesis. This I shall outline very briefly.

I. Minerals of the deep-seated rocks are prevailingly silicates. These silicates are unstable when exposed to the atmosphere and hydrosphere. Water, carbon dioxide and oxygen enter into combination with metals of the silicates; these compounds thus are de-

stroyed, and oxides, carbonates and various hydrated minerals are formed.

Some decrease in the quantity of these constituents of the atmosphere and hydrosphere must therefore result. Limestone and coal record abstraction of carbon dioxide from the air in enormous amounts in the past.

II. Carbon dioxide, 3/10,000 by weight of the atmosphere to-day, is remarkable in its ability to prevent the escape of "dark heat" from the earth, while permitting the sun's radiant energy to reach the earth. Calculations indicate that to double or to halve this insignificant quantity would raise or lower the average temperature of the earth's exterior by 2° C. This may not seem a very great change, but compare it with the estimates that a lowering of our present average temperatures by 5°–8° C. would reestablish ice sheets over half of North America.

III. The oceans to-day are filled with nearly ice-cold water, even in equatorial latitudes. Only the surface film in the lower latitudes is warm. Cold water settles near the poles, and very, very slowly spreads out over the ocean floors. This is because cold saline water is slightly heavier than warm saline water. The difference in density is very slight, indeed. Were there more widespread oceans, freer entrance of warm waters into higher latitudes and a better thermal blanketing of the whole earth, the contrast would be still less.

Professor Chamberlin suggests that perhaps under such conditions (the conditions of the middle of a typical geological period) density contrasts due to differences of salinity, instead of differences of temperature, might control the great slow overturn of the ocean waters. In such case, greater evaporation (to produce greater salinity) in low latitudes would locate the region of descending waters where they would be warm waters. The deeper parts of the oceans then would become filled with warm, instead of cold, water. The effect of such a situation on world-wide climates is obvious. This would occur in the middle of a geological period when the water-heating plant of the earth would function in its highest efficiency.

IV. Let us now consider the situation toward the close of a typical geological period. A long quiescence of diastrophism has preceded and the spreading epicontinental seas have greatly reduced the land areas. Such as remain are low, featureless and covered deeply with a mantle of the products of decomposition of the underlying rocks. The climate is mild and equable in all latitudes.

But stresses engendered by the shrinking interior have been accumulating during this long quiescence and finally they exceed the

resistance of the great earth body to deformation. A revolution is imminent and unavoidable. As diastrophism awakens, the seas are rapidly withdrawn into the deepened ocean basins, the new lands are uplifted and locally squeezed into massive and lofty mountain systems. Gradients are steepened, erosive forces are more active, the protecting mantle of soil is swept away and unweathered rock is widely exposed. Much of this rock is silicate material and is immediately attacked by the active constituents of the atmosphere.

The draft on atmospheric carbon dioxide would be very great under these conditions, and depletion would lower the average temperatures of all latitudes. Colder air will hold less water vapor and water vapor is even more effective than carbon dioxide as a thermal blanketing agent. Thus the result of decreasing the carbon dioxide would be greatly multiplied. Lowering temperatures of the oceans would give them greater capacity for absorption of atmospheric carbon dioxide and the situation would become still more aggravated.

At this time should come a reversal of oceanic circulation, the cold polar waters now settling and filling the oceans. At such time we should have:

(1) Interrupted atmospheric circulation, because of mountain ranges, and because of permanent high pressure areas over the extensive lands;
(2) Interrupted hydrospheric circulation, because of emergent continents and land bridges;
(3) A less efficient blanketing action of the atmosphere, because of decreased carbon dioxide and water;
(4) A less efficient water-heating action of the oceans, because they are filled with cold water.

Now, the evaluation of such a situation would be extremely difficult. Would the continental climates over the large land areas, untempered by warm oceans, be adequate for glaciation or aridity, the local conditions to determine which? The best way to answer the question is to go to earth history. Here we find that glaciation and aridity have occurred when, and almost only when, this combination of conditions has been realized. And certainly our present-day glaciation and aridity conform to these conditions. We are living in one of these times of extensive and elevated lands, restricted seas and cold-water oceans, and immediately following or in the waning stages of a time of diastrophic adjustment in the body of the earth.

We therefore argue that not alone the alternation of erosion and sedimentation on the continents, the periodic diastrophism and the notable faunal changes, but also the great climatic oscillations of earth history are due to telluric energy, and record an earth body not in complete internal adjustment.

To correct this glacial and arid condition, we must wait on two things:

One, the progress of the new cycle of erosion which eventually
(1) lowers the lands to such gradients that deep soils accumulate and check further carbonation of the silicate rock, and
(2) brims the oceans over on the continents, and decreases the area of land exposed;
Two, the cumulative effect of vulcanism which discharges carbon dioxide into the air, and eventually makes good the loss sustained.

Vulcanism

Vulcanism is one of the great problems of geology. Its status is less advanced and less satisfactory than that of any other I have mentioned thus far. More diverse ideas have been proposed to explain it, more are entertained to-day, than in any other phase of geology. The chief reason for this is that we have fewer data on vulcanism than on any other geological process or group of related phenomena. All explanations of vulcanism, of any merit, must recognize that the rigidity of the earth as a whole proves the absence of a universal molten condition of the interior. Yet liquid rock, flowing almost as freely as water, comes from places in this earth. We are forced to the conclusion of limited magma basins. That these are of long duration, geologically, seems doubtful. Magma basins seem to be determined by favorable conditions of composition, pressure and temperature. As these conditions may change, so the location of magma basins changes. The depth from which lava comes is also unknown, though most opinion places its generation in quantity at no great depth. Some would have it the product of the superficial wrinkling which we call mountain-folding, and thus generated very close to the surface of the earth.

What is the origin of the earth's internal temperatures? The modern view has it that it is secondary to the origin of the earth. It may be due: (1) To physical condensation of the earth, or (2) to chemical reactions forced by the physical condensation, or (3) to radioactivity, or (4) to some combinations of these causes. At any rate, the actual temperatures of the interior depend on the ratio between the rate of evolution of heat and the rate of conduction and radiation of this heat into outer space. Geothermal gradients we possess for only 1–4000 of the total radius of the earth. The temperature curve for 3999–4000 is unknown. And the measured gradients vary greatly, due to local conditions: (1) chemical changes going on in the rocks; (2) original temperatures of lava rock, still retained; (3) circulation of deep-seated water, versus meteoric water.

The force which raises lava to the surface is hydrostatic. The

proverbial violence of volcanic behavior is wholly a matter of gases expanding near the surface. The lava stands quietly in, or flows quietly from, such craters as Mauna Loa and Kilauea. And only in small measure do the Hawaiian volcanoes have associated gas phenomena.

What determines the place of eruption of lava? In general, fracture and folding of the lithosphere are held responsible. Magma is probably passive, perhaps only potential, at great depths. Diastrophism may generate heat locally to cause liquefaction, or may decrease pressure by arching, or both. As a consequence, lavas are frequently extruded in regions or folded mountains during their growth. The deeper the folding, the greater likelihood of igneous extrusion. Yet great extrusions have occurred without the known accompaniment of great diastrophism. The mechanics of such vulcanism is obscure. To enter this field is to venture into pure speculation, and demands the utmost hardihood.

Far more significant than the explosive behavior of volcanic gases is the question of their further history. They are contributions to the atmosphere and hydrosphere. It is largely held to-day that our present oceans and atmosphere are volcanic in origin. The carbonation, oxidation and hydration of rocks during gradational history has abstracted enormous quantities of carbon dioxide and oxygen from the air. The limestones contain many thousand times the amount of carbon dioxide now in the atmosphere, and all of it has been taken from the air. Yet there is no evidence that the air has ever contained much more than it now does.

That atmospheric carbon dioxide is essential to life is obvious. There is as much now contained in the bodies of plants and animals as there is in the atmosphere. That there is constant withdrawal of carbon dioxide from the air has been indicated. Vulcanism has renewed the supply. It follows, therefore, that the emission of volcanic gases, operative through geological time, has been a fundamental condition for the continuance of living matter.

Has vulcanism been rhythmic in earth history? In a general way, yes. It has been spasmodic and much of it is traceable to diastrophism, to which it appears to be subordinate and consequent. No progressive tendency is detectable: (1) In chemical composition of extruded lavas, (2) in modes of eruption, or (3) in degree of activity, since the beginning of the Proterozoic era. Vulcanism, therefore, seems to be a consequence of the lack of physical and chemical equilibrium of the earth body. When that equilibrium is eventually attained, in the far distant geological future, both diastrophism and vulcanism will cease and gradation will attain its final and complete triumph.

The Age of the Earth

We have now reviewed very briefly the part played by the great geological processes during the recorded existence of the earth. One final question arises: "How long has this interplay been going on?" "How old is the earth?"

Estimates vary! Archbishop Usher set the beginning at 4004 years before the birth of Christ, but this figure does not seem to have an adequate basis of observed and properly interpreted fact. Practically every estimate since his time has been greater than the preceding one until to-day we have estimates for the age of the oldest rocks mounting to the stupendous total of a billion, five hundred million years. And the later estimates are based on better evidence than the earlier.

What kind of evidence lends itself to the making of such estimates? I will note briefly three methods of approach to the problem:

I. The ocean salts,
II. The thickness of the sedimentary rocks, and
III. Radioactivity of igneous rocks.

Meteoric water, flowing over and through the rocks of the land, dissolves material and removes it in solution to contribute it to the ocean. Of all the substances dissolved in ocean water, sodium chloride alone tends to accumulate. All others enter into detrital or organic or chemical sediments. For example, calcium carbonate, though much the most abundant substance carried to the sea by rivers, yet in percentage in ocean water is almost negligible. Marine organisms use it in building their hard parts, and after their death, it goes into the sediments.

If we know the total amount of sodium chloride in the sea, and the total annual contribution by streams, it is obvious that division of the larger figure by the smaller would express in years how long the process has been going on; *i.e.*, the age of the oceans, and therefore the length of recorded geological time.

But you see at once that there are several weaknesses in this method.

(1) The area of lands in the past, on the average, has probably been considerably less than at present.

(2) Stream gradients, and therefore vigor of search for soluble substances, has not always been that of the present.

(3) Sodium chloride may be dissolved from rocks at the strand line, by the waves. The solvent power of sea water is said to be about six times that of fresh water.

(4) Sodium chloride may have been leached from the rocks beneath the oceans. Three fourths of the lithosphere now is submerged.

(5) Some sodium chloride has been precipitated out of ocean water in the past. Witness our rock salt beds, clearly of marine origin.

(6) Cyclic salt, escaping from the oceans in wind-blown spray, is in streams but in unknown quantity.

(7) Salt in streams from human contamination, in unknown quantity. A high content of sodium chloride in a stream analysis almost invariably means Homo sapiens somewhere upstream.

(8) Juvenile waters (volcanic waters) with their unknown saline contributions.

(9) Connate waters (fossil sea waters) return via the streams. What amount is to be deducted for this factor?

Evaluating these factors as best we may, the different computations give in round numbers one hundred million years for the age of the oceans.

But a safer plan seems to be to neglect all the sodium chloride and compute on the basis of the unchloridized sodium now being contributed from areas of igneous rocks, and assume that the chloridization occurs after the sodium enters the sea. Most of the chlorine in the salt has not come from leaching of rocks anyway. The igneous rocks do not yield, nor possess, enough chlorine to make the salt of the sea. We assume that this chlorine has come from volcanic gases. Computing on the basis of the unchloridized sodium, the stores of sodium chloride now in the oceans would demand 180 million years for their accumulation. This method also is open to some of the objections to the sodium chloride computation.

One of the earliest, and apparently one of the simplest, methods of estimating geological time is based on the total observed thickness of all geological systems now exposed, and dividing this by the rate at which they have been deposited.

There is no great difficulty in getting the figures for the maximum thickness of all geological systems now exposed. They are commonly quoted as about 70 miles, not including the sediments in the Archean complex.

But the rate of sedimentation—there's the rub! Sedimentation near the mouths of large and active rivers must be much more rapid than along coasts without them. Sedimentation near shore must be much more rapid than far from shore. Sedimentation in the accumulation of a limestone must be much slower than in deposit of a clastic rock. Nothing better than a rough estimate can be used for our problem. And this must vary with the personal equation of the individual computer. As near to an average as I have been able to get is one foot of sediment (all kinds averaged in terms of their relative abundance in the stratigraphic column) in 880 years. This demands three hundred million years for the accumulation of the sedimentary pile.

But what of the unconformities which are present in the sedi-

mentary series? The torn-out page of the book of earth history? The duration of the periods of erosion, recorded by unconformities, is unknown, save that they were long enough for notable biological changes to occur and for extensive peneplanation to occur.

Furthermore, the sediments which we examine and whose thickness we measure were deposited in the shallow waters on the continental shelves. During times of widespread emergence of the continents, detritus from the lands has gone off the edge of the platforms into the abyssal depths and is now inaccessible. Its thickness is unknown.

Still further, let us note that when sedimentation in these shallow epicontinental seas has filled them until their bottoms are close to the level of wave-base, the agitation of the waves and undertow will allow no further deposits to occur. Instead, any sediment contributed will be carried off to deeper water. But will any record of this condition appear in the sediments? These diastems, when neither erosion nor sedimentation was going on in the epicontinental waters, are impossible of evaluation. Some think that they are of great importance in interpreting the record.

Any estimate of the duration of geological time from a study of the sediments must, therefore, be some multiple of the three hundred million years before noted. Perhaps six hundred million, perhaps nine hundred million!

In 1896 Roentgen discovered the X-rays and set the scientific world agog. A year later Becquerel discovered the phenomena called radio activity and the next year Madame Curie isolated radium. Perhaps never in the history of science were more significant discoveries made in so short a time, and were more theories sentenced to the guillotine. The whole conception of the structure of matter had to be remade, a new physics and a new chemistry arose. It is not my purpose, nor my ability, to go into a discussion of the fundamentals of radioactivity. I shall simply indicate the significance of these new discoveries in the problem of the age of the earth.

Radioactive substances are derived from the body of the earth. The parent sources are the uranium and thorium minerals. Each of these elements slowly and regularly breaks down, and liberates alpha, beta and gamma rays, by which the decadence and disintegration may be noted and measured. In the breaking down of uranium, helium is continuously and lead is eventually produced. The end produce of 1Ur is 8He and 1Pb. There are several intermediate stages of the products. Radium is one of these, but its half-value period is only 1660 years, and where found in the rocks, it is a relatively recent product and can not be used in estimating

the age of the earth. But the half-value period of uranium is 6×10^9 years, or six billion years.

How can we use these phenomena in attacking our problem? If we have an igneous rock which contains uranium and helium and lead, and if all the lead and helium present are the product of disintegration of uranium, and if all the lead and helium produced by this disintegration are still contained in the rock, the age of the rock may be obtained.

Use of the helium consistently gives much smaller figures than use of lead for calculations. This is to be expected since the helium constantly leaks away while the inert lead remains.

Another method of using radioactivity for estimating the age of the earth is possible. It is in the study of pleochroic halos. Pleochroic halos are tiny circular spots of color seen in thin section in certain minerals of igneous rocks, under the compound microscope. Each halo has as its center a minute inclusion of radioactive matter. The halo is caused by the discharge of positive electricity by helium atoms (alpha particles) at the end of their trip. Alpha particles from uranium travel with less velocity than those from radium. There is still another rate for the helium atoms from thorium. And the radii of the different rings in the halos correspond exactly with the relative velocities of helium from the different radioactive substances in the nucleus.

Furthermore, artificial pleochroic halos have been made by duplicating the conditions in the rocks, in all but two factors—time and degree of radioactivity.

Now, if a halo of a certain intensity of color can be made in a certain time by a certain high degree of radioactivity, and if the radioactivity of the nucleus of the natural halo is known (it will be low, of course), we may compute the age of the rock in terms of years. That is, the time since the igneous magma solidified and crystallized. Igneous rocks have been formed at various times in the history of the earth. Since they contain no fossils, their age in terms of period and era must be learned by their relations to the fossiliferous sediments. If we can date them in years, we can say how long ago such and such a period occurred.

Not many computations on this basis have yet been made, but nearly all thus far made possess the right relative values. As to actual figures, you will be interested chiefly in the statement that the two geologically oldest granites studied appear to have crystallized from a molten condition 1,125 million and 1,500 million years ago. And these granites may not be older than the oldest sediments!

THE FUNCTIONS OF THE ENDOCRINE ORGANS[1]

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ENDOCRINOLOGY enjoys the distinction of having a definite birthday. On June 1, 1889, Professor Brown-Séquard, then a man of 72, reported before the Paris Société de Biologie a series of arresting observations on the invigorating effects of testicular extracts upon himself. Subsequent work indicates that suggestion probably played a considerable part in the results as set forth, but such was the eminence of the observer and so significant seemed the theory underlying his work that endocrinology became, almost over night, a subject of world-wide interest. The meager annual dribble of endocrine contributions was soon swollen to a flood which has poured forth with increasing volume ever since. In the current (1922) edition of Biedl's well-known "Innere Sekretion" the bibliography alone comprises 480 closely set pages, and only the presumably more significant articles are listed.

To an unusual degree important fundamental discoveries in this field have come from clinical observations. Addison's description of the disease that bears his name includes a large proportion of the most significant facts we have regarding the adrenal glands. Although Schiff's earlier experimental observations, had they commanded adequate consideration, might have been very enlightening, it was actually the clinicians, Friedrich Müller, Murray, Ord, Gull and Kocher, who opened up the field of thyroid physiology. Our first substantial knowledge regarding the physiology of the hypophysis came from Marie in connection with his observations on acromegaly. Thus we have the unusual spectacle of practicing physicians inducting physiologists into important fields of physiology. The debt of gratitude we owe it is a pleasure to acknowledge. It may not be too ungracious, however, to remark that this reversed gradient has proved by no means an unmixed blessing. The apparent fertility of the endocrine field and its ready accessibility soon attracted a numerous band of husbandmen who had neither the time and patience nor the critical acumen for its successful tillage. Accordingly, a large body of literature has accumulated which, for its vagaries, fantastic exuberance and wholesale marvel

[1] Read before Section N (Medical Sciences) American Association for the Advancement of Science, at Cincinnati, December 29, 1923, in the symposium on the endocrine organs.

mongering is perhaps without a peer in the history of modern science.

In all truth, however, the substantiated reality is wonderful enough. When we see misshapen, stunted imbeciles transformed to normal, happy children, diabetics starving in the midst of plenty restored to health and strength, giants and dwarfs produced at will, sex manifestations engendered or reversed before our eyes by control of endocrine factors, who can regard endocrinology as other than a most significant phase of modern biology?

The ultimate aim of science is the control of nature. That part of nature in which most of us are preeminently interested is the human mechanism. That this is subject to the sway of nervous impulses has long been recognized. In addition to nervous control, however, every organ of the body is affected in its development and its functioning by chemical regulators. Of these, the hydrogen-ion is so important that a deviation in the acid-alkaline balance of the blood no greater than that between tap water and distilled water is fatal. The potency of certain of the chemical substances, the hormones, elaborated by the endocrine organs, is as striking as that of the hydrogen-ion. For example, adrenalin, a substance constantly being made in our own bodies, exercises a clean-cut influence when applied to various tissues in a dilution of one part in a hundred millions. Under favorable conditions intestinal motility has been shown to be significantly depressed by a dilution as high as 1 : 330,000,000. Luden has graphically illustrated the meaning of this statement. Modifying her illustration somewhat, suppose we set out to dilute an ounce of pure adrenalin crystals with water to a point at which the drug can no longer be detected by the intestine assay method. The necessary water will be conveyed in ordinary street sprinkler tanks holding 625 gallons each. The tanks deploy in procession at intervals of about 25 feet, or 200 to the mile. When the contents of each tank in a procession extending 20 miles has been poured into the ounce of adrenalin the reaction will have just disappeared. At the meeting of the American Physiological Society this year Abel reported the isolation of a product from the pituitary which is even more potent. To dilute an ounce of this to the ineffective point the procession would have to be not 20 but 1,000 miles in length. In case of a highly sensitive test tissue the procession would have to be more than 5,000 miles in length. These quantities, it may be emphasized, involve no element of the fanciful; they are realities. Such magnitudes almost bring endocrinology into kinship with astronomy.

An adequate consideration of any one of numerous phases of the physiology of any one of several different incretory organs would more than exhaust the time available for this address. It is possible

to cite but a few interesting observations. The necessity of ignoring many important recent studies is regretted.

The Pineal

Proceeding from above downward we may first mention the pineal body, a structure homologous with the parietal eye of certain extinct lizards. It is formed as a dorsal evagination of the midbrain. Descartes taught that the organ is the seat of the soul. The pineal reaches its greatest development, however, by the age of seven and then recedes, a fact hardly consistent with Descartesian theology. The literature on pineal function is equivocal. There are a few clinical cases recorded in which apparently destructive tumors of the gland have been associated with premature development of the body and the sex organs, a condition formidably indicated by the octopedalian vocable, *macrogenitosomia precox*. Attempts to produce a similar condition experimentally have been attended with many difficulties. The most favorable subjects for such work are fowls, because of their well-marked sex stigmata and the relatively easy approach to the pineal. Rather a respectable number of investigators have obtained augmented growth and precocious puberty after pinealectomy in this form. In rats, Horrax, in 1916, obtained rather doubtfully positive results, but after careful extirpation of the pineal in puppies Dandy more recently has obtained convincingly consistent negative results. In both clinical and experimental investigations the possibility of local brain involvement rather than of pineal deficiency as the essential causal factor has to be considered and has not been ruled out.

Feeding experiments have given varying results in the hands of different investigators. The trend of the evidence, so far as it is of positive tenor, indicates that pineal feeding, just as pineal destruction, causes precocious development. In view of the negative results in a considerable number of careful investigations one might be led to suppose that pineal substance is only inert organic débris, that the rather indefinite positive results secured from its administration are to be ascribed to coincidence, were it not for the report of McCord and Allen and more recently of Huxley and Hogben that it causes a sharp contraction of the chromatophores of tadpoles, giving them a peculiar translucent, ghostly appearance.

It is to be noted that in this as in all cases negative results from the administration of gland substances are of practically no final significance because of the uncertainties involved in the preparation of the gland material. An organ might conceivably exercise an important incretory function without at any one time containing more than a trace of its specific hormone. Moreover, even if the hormone were present in fairly high concentration it might all dis-

integrate quickly after death or be destroyed in the process of manufacture of the gland product. The ideal check on these possibilities is to demonstrate the presence of the given hormone in the blood or lymph flowing from the organ. This has not as yet, however, been accomplished with certainty in case of any but the adrenal glands.

The Hypophysis

The hypophysis is a composite organ formed embryologically by an outgrowth from the primitive pharynx meeting and investing an outgrowth from the ventral side of the brain to which it remains attached by the infundibular stalk. In postnatal life it is located in almost the exact center of the head. The pharyngeal component is epithelial in nature and comprises the anterior lobe, the pars intermedia and the investing layer of the posterior lobe and stalk. The posterior lobe is made up mostly of neuroglia which supposedly have only a mechanical, supportive function. Paradoxically, however, it is from the posterior lobe that the potent secretion often referred to as pituitrin is secured. It is probable that the pituitrin is actually formed by the epithelial cells of the pars intermedia and more or less as a matter of accident concentrated in the neural lobe en route to the third ventricle of the brain, where it is added to the cerebro-spinal fluid.

It was formerly believed by many endocrine students that complete extirpation of the hypophysis is necessarily a fatal operation. That this is not the case, however, has been shown rather conclusively. Recently, Brown, of Chicago, has removed the glands by cautery from 66 dogs. Many of these survived and developed characteristic symptoms, but in five cases no symptoms whatever could be detected following the operation, although careful microscopic study of the tissue about the original site of the hypophysis failed to disclose any remnants of it.

In many cases a depression of growth that seems to amount to dwarfism results from pituitary extirpation. This finding is concordant with the fact that in the Levi-Lorian type of dwarfism in man pituitary hypoplasia seems to play a causal rôle.

The condition of *dystrophy adiposogenitalis* often resulting from hypophysis extirpation has been recognized clinically for nearly a century. It was first described, though not in an entirely typical form, by Mohr in 1840; its association with hypophyseal lesions was recognized by this observer. It was through the work of Fröhlich, however, that it became generally recognized as a definite clinical entity. In the Fröhlich syndrome in man the fat tends to have a peculiar distribution, being especially marked in the mammary region and about the pelvic girdle. A high tolerance for carbohydrate, metabolic sluggishness, flabby musculature and some-

times somnolence are characteristically found. Dickens's "Fat Boy," "Joe," was obviously a victim of this malady. Polyuria or *diabetes insipidus* is frequently but not invariably an accompanying symptom. Although sexual infantilism is commonly seen, the sex organs may be fairly well developed, but axillary and pubic hair growth depressed and in the male show the feminine type of distribution.

Many clinical observers believe that the Fröhlich dystrophy is due, not to general hypophyseal defects, but exclusively to involvement of the posterior lobe and the pars intermedia. The evidence for this belief is not convincing, however, and some doubt is cast upon it by reported beneficial effects of administering anterior lobe substance in the Fröhlich dystrophy.

Indeed, recent work has opened the question whether any part of the pituitary is involved in this condition. Leschke, Houssay, Camus and Roussy and more recently Baily and Bremer, working in Cushing's laboratory, have shown conclusively that the adiposogenital dystrophy in its classical form can be produced merely by injury of the tuber cinereum, a part of the base of the brain lying near the attachment of the pituitary stalk. In various cases of the full-blown dystrophy no microscopic evidence of pituitary injury could be detected. The possibility remains, however, that the brain injury may have involved secondary trophic disturbances in the hypophysis.

A great deal of work has been done on the pharmacology of pituitrin. Houssay, of Buenos Aires, has published a monograph of 350 pages on hypophyseal extracts, most of which is concerned with pituitrin. This substance injected parenterally or directly into the blood stream causes a marked stimulation of the heart and the smooth muscle throughout the body. Among other effects, this results in augmented blood pressure and increased gastro-intestinal activity as well as uterine contractions, especially in pregnant animals. For brief periods in anesthetized animals pituitrin causes an augmented flow of urine, usually with vascular dilatation in the kidneys. Paradoxically, however, its effect in the intact, unanesthetized subject is to check diuresis, either that induced by copious administration of fluids or that spontaneously arising in diabetes insipidus. Rogers has noted that in pigeons rendered poikilothermous by injury of the optic thalamus pituitrin causes a marked rise in body temperature. In normal animals, however, the thermogenic effect falls within the limits of diurnal variation. Achard and others have shown that pituitrin injections cause a considerable rise in blood sugar. Burn has recently shown that the dangerous fall in blood sugar resulting from an overdose of insulin can be promptly relieved by pituitrin.

Attempts to demonstrate the existence of a physiologically active substance in anterior lobe material have until recently given negative or at least unconvincing results. Robertson described an extract, *tethelin*, as an active principle which has a marked influence upon growth. The work has, however, failed of satisfactory confirmation. It is now regarded as a variable mixture of lipoids. In a few instances Goetsch noted greater reproductive activity in rats receiving anterior pituitary substance than in their controls, but his controls appear not to have been normally fertile. Numerous other investigators have obtained negative results in such experiments. Uhlenhuth, however, in *Amblystoma tigrinum* succeeded in producing giants by feeding anterior lobe substance from cattle. His experimental animals were 25 per cent. larger than the largest normals which he was able to rear or to find in other collections. The growth of tadpoles delayed by extirpation of the hypophysis has been shown by Smith and by Allen to be markedly stimulated by injections of anterior lobe extract, the experimental subjects outgrowing their normal controls about twofold. Similar results were obtained by Allen and by Swingle from anterior lobe transplants. The latter observer has reported that the tadpoles of two species of frogs which normally remain in the larval stage for long periods can be made to metamorphose promptly by ingrafting anterior lobe of the hypophysis of adult frogs. This effect is apparently correlated with the marked hyperplasia of the thyroid that ensues. Smith also has recently reported a similar thyroid hyperplasia in tadpoles following injections of anterior lobe extract. Particular interest attaches to the work of Evans and Long on the effects of bovine anterior lobe extract in rats. These observers were able to demonstrate conclusively an overgrowth that can fairly be described as gigantism.

Corroborative of experimental findings are the facts that the sella turcica of the sphenoid bone in which the hypophysis is located is enlarged in spontaneous gigantism and decreased in some cases of dwarfism. Acromegaly, a condition arising with hypophyseal enlargement after puberty in man, has not been reproduced experimentally.

The Thyroid

The outstanding features in the physiology of the thyroid gland are so well known as scarcely to need discussion. Thyroid deficiency of extensive degree often appears spontaneously and can readily be produced experimentally. The subject, either human or other mammal, remains a stunted, pot-bellied, bandy-legged imbecile. It exists on a low metabolic plane, as is evident from its sluggishness, reduced body temperature with susceptibility to cold, dry hair and skin, and failure of sexual development. Lesser degrees of thyroid

deficiency, gradually merging into normality, with correspondingly developed symptomatology, can be recognized. That the conditions are due directly to thyroid deficiency can be demonstrated by the complete restoration to normality by thyroid feeding. It should be noted, however, that if treatment is too long delayed deterioration may progress to a point no longer amenable to correction.

Perhaps the most remarkable result of thyroid administration is its stimulation of growth. In so-called cretins several inches increase of stature in a year is not uncommon. Moreover, the leanness of certain hypothyroid subjects can be strikingly ameliorated by thyroid treatment. These characteristic anabolic effects of the thyroid hormone are often forgotten in endocrine philosophizing.

If thyroid substance be administered in amounts much surpassing the normal or if the gland spontaneously becomes greatly overactive symptoms of intoxication arise. The oxidative processes of the body are increased, sometimes 100 per cent. Other characteristic results are tremors, rapid pulse and nervous excitability often leading to stubborn insomnia.

The isolation by Kendall of a potent, chemically constant, iodin-containing substance, *thyroxin*, has rendered possible some interesting quantitative studies. There is considerable evidence that thyroxin represents a true "active principle." From studies on hypothyroid human subjects data have been obtained indicating that the amount of thyroxin in the adult body outside the thyroid gland is approximately one fourth of a grain. About one one hundredth of a grain a day is required for normal health. It is startling to contemplate that about three and a half grains of this substance a year is all that stands between any of us and imbecility. The effect of a single dose of thyroxin develops slowly and persists for from two to three weeks.

The thyroid is subject to seasonal influences; it shows evidence of depression during the warm months and of increased activity in winter. It reacts quickly to changes of diet. In old age gradual deterioration of the thyroid characteristically occurs. Whether, however, this is cause or effect presents an interesting problem. There are in the literature a number of reports of amelioration of the signs of senility following administration of thyroid substance, but the problem needs further study.

These are but a few bits from a large body of evidence. The time is not yet ripe for a definite generalization, but it seems probable that the function of the thyroid gland is to serve as a slowly acting regulator of energy discharge to aid in adapting the animal to its environment.

The Parathyroids

The parathyroid glands in man are four in number, situated in close relation to the thyroid. In the adult they are about the size of peas. Removal of the glands commonly results in a characteristic condition, *tetania parathyropriva*. Objectively, this is marked by tremors, clonus and various degrees of muscular contracture. The galvanic excitability of the motor nerves is augmented to an extent more or less paralleling the degree of glandular deficiency. In some cases tetany fails to appear, but the subject may develop cachexia. Defects in development of the teeth often occur, a fact probably correlated with disturbed calcium metabolism. Salversen has recently confirmed older reports that the amount of calcium in the blood in this condition is considerably decreased. That calcium administration materially alleviates parathyroid tetany is well known.

The classical symptomatology of parathyroid deficiency suggests intoxication. Koch, followed by Paton and his collaborators, found in the urine methyl guanidine, a substance closely related chemically to creatin. Injection of methyl guanidine was found to cause augmented neuromuscular irritability. This is not, however, amenable to calcium treatment as is parathyroid tetany. Hammett has found that excitable wild rats are much more susceptible than gentle subjects to parathyroidectomy. This fact he tentatively correlates with increased creatin formation associated with augmented muscular tonus. Whether or not methyl guanidine be a significant factor, it seems clear that some sort of toxin is involved. Luckhardt, Dragstedt and their associates have shown that measures directed toward preventing toxin absorption from the alimentary tract and facilitating prompt elimination are highly efficacious in controlling parathyroid tetany. The omission of meat from the diet, avoidance of constipation and the copious use of fluids may suffice to keep a dog in excellent health despite complete parathyroidectomy. Such animals can even go through pregnancy without disturbance, although this condition ordinarily causes marked accentuation of symptoms and, indeed, frequently death.

Although parathyroid extracts have been widely used therapeutically, there is no very satisfactory evidence of their potency. Parathyroid grafting has as yet led to few if any convincing results.

The Adrenals

Speculative endocrinology of recent years has largely centered in the adrenal glands. Despite a very large body of careful observations these organs remain a mystifying puzzle. The adrenals are situated at the anterior poles of the kidneys. In size and shape they resemble large beans. Like the thyroid, they are richly vascu-

larized. Each gland consists of two parts, a cortex and a medulla. Destruction of the whole gland or of the cortex in most animals is rapidly fatal. In some animals, however, enough accessory adrenal tissue is present to prevent death. In the absence of the adrenals the subjects develop muscular weakness, low blood pressure and fall of body temperature. In the hands of most investigators attempts to produce partial functional inadequacy of the glands have not been successful; either no detectable effects are secured or the animals promptly die. There is some evidence, however, that trophic disturbances, particularly of the skin, may develop as a result of a properly graduated adrenal deficiency.

Numerous attempts have been made by extirpation experiments to differentiate between the functions of the cortex and the medulla of the gland. Biedl, for example, studied the problem in certain fish in which the two structures constitute separate organs. The results indicated that it is the cortex that is essential to life. Several investigators have lately attempted to determine the matter in higher animals, especially dogs. With a curette or cautery the central, medullary part of the gland has been destroyed. It is, of course, necessary in such studies to check microscopically the amount and distribution of the destruction. In general, the results have been consistent in showing that animals survive the complete loss of the medulla, but that when the cortex is reduced below a critical amount death supervenes. This is a surprising fact, because it is from the medulla and not the cortex that the recognized active substance in adrenal extract is derived.

There are on record a considerable number of cases, mostly human, in which spontaneous hyperplasia of the adrenal cortex has been associated with the condition of virilism. In young males this is manifested by precocious puberty; in older subjects hirsutism is the chief objective sign. In females it is said that the normal sex stigmata may be accentuated, but more often the subject becomes masculinized. The condition is reported to be often associated with marked increase of bodily strength. Extracts of adrenal cortex have not been proved to be effective.

From the medulla of the gland, however, and to a much less extent from outlying chromophil tissue associated with the sympathetic ganglia the substance, adrenalin, is secured. This is a powerful stimulant of the sympathetic nervous system. It causes augmentation of the heart beat and of other functions stimulated by the sympathetics. The gastro-intestinal tract, however, is inhibited by adrenalin as it is by sympathetic stimulation. There is evidence that the ganglion cells are affected to some extent, but most of the influence of adrenalin is exerted upon a hypothetical "re-

ceptive substance'' interposed between the sympathetic terminals and the effector cells.

One of the most striking reactions to adrenalin is increase in the amount of sugar in the blood. This is probably due largely to stimulation of the liver cells. The terminal bronchi in the lungs are dilated and the respiratory center directly or indirectly stimulated. Basal metabolism is materially increased by subcutaneous injections of as little as 0.5 mg in an adult human subject. There is a mass shifting of the blood from the splanchnic domain and the skin to the skeletal muscles. The efficiency of the skeletal muscles, at any rate in cats and dogs, can readily be shown to be increased by the injection of adrenalin. The recovery from fatigue or asphyxia is much accelerated. In the cat, as Gruber has shown, it is possible by perfusing it with adrenalin to resuscitate skeletal muscle even two hours after death so that it will respond vigorously to stimulation. The coagulation time of the blood is lessened by adrenalin in physiologic doses.

Cannon has offered a theory that pain, fear, rage and asphyxia, conditions attendant upon emergencies arising in the environment, cause augmented adrenal discharge. This is the so-called *emergency theory*. As Cannon points out, the aforementioned reactions to adrenalin would all be of adaptive value in enabling the animal to go safely through a conflict with an opponent.

The history of the vigorous controversy that has arisen over the emergency theory serves to illustrate the difficulties attending investigation in the field of endocrinology. After more than ten years of exacting study by some of the world's foremost physiologists wide divergence of views still maintains. The problem is essentially that of control of adrenal discharge. That stimulation of the sympathetic fibers going to the adrenals evokes adrenalin discharge is an unquestioned fact. That the glands are under central control is rather convincingly demonstrated. That pain, strong emotions and asphyxia cause a marked overflow of impulses through the sympathetic system is generally recognized. The assumption that the sympathetic fibers going to the adrenals share in the reaction to the conditions mentioned has an inherent probability little short of conclusive. Final irreproachable proof of this assumption, however, has been difficult to secure. Numerous observers have reported bodily changes such as are produced by the injection of adrenalin when the experimental animal has been subjected to strong sensory stimulation or to asphyxia. In most reported cases removal of the adrenal glands has materially lessened or abolished these reactions. In some instances, however, ambiguous or negative results have been secured. The most recent extensive investigation of the problem reported is that of Kodama. In this study the ''vena cava pocket''

method of Stewart was employed, the efferent blood from the adrenals being collected and assayed outside the body. Stewart, the most vigorous opponent of the emergency theory, maintains that this is the ideal method of studying the problem. In most of Kodama's animals clean-cut evidence of increased adrenal output, often more than 100 per cent., was obtained after strong stimulation of sensory nerves.

The greatest obstacle to the solution of the problem would seem to lie in the fact that reactions to adrenalin are conditioned by a number of factors often overlooked. In the case of blood pressure, for example, adrenalin may cause an increase or a decrease, depending upon dosage, speed of injection, initial blood pressure, body temperature, hydrogen-ion concentration of the circulating medium, presence or absence of tissue extractives and perhaps conditions in other endocrine organs, especially the thyroid. Under such circumstances uniform results would be by their very consistency suspect. Before any crucial experiment either favoring or opposing the emergency hypothesis unless perhaps the direct assay method can be accepted as final it must be shown that the aforementioned conditioning factors are controlled. That this could be conclusively shown is doubtful. It seems obvious that the problem should be attacked on a statistical basis. One gathers the impression from the pertinent literature as a whole that the data mathematically treated would show a high correlation between presence or absence of the adrenal medulla and the vascular reactions to pain or asphyxia.

Pende has recently attempted to revive the so-called tonus theory of adrenal function. In view of the facts that adrenal deficiency results in striking fall of blood pressure and large doses of adrenalin cause a remarkable rise the plausible assumption was widely held for two decades that the essential function of the adrenal glands is to maintain sympathetic and, especially, vascular tonus. The theory assumes that the adrenal glands are constantly discharging adrenalin in minimal pressor quantities. Superficially attractive as the theory is, it fails to accommodate certain facts. If the glands are constantly pouring out pressor quantities of adrenalin, a notably evanescent substance, sudden occlusion of the adrenal veins should result in a prompt fall of blood pressure except in those occasional instances in which a free collateral outlet through the kidneys is open. But a depressor effect is not seen for hours after adrenal occlusion if the initial blood pressure is anywhere nearly normal. If the adrenal glands are constantly discharging minimal pressor quantities of adrenalin the injection of a slightly greater amount should lead to increased blood pressure. A fall of pressure, as a matter of fact, results. Adrenalin, in addition

to having a pressor influence, is a potent paralysant of gastro-intestinal motility. The threshold of this paralysant effect is lower than the vascular pressor threshold, hence adrenalin could directly maintain blood pressure only at the expense of intestinal ileus. An alternative version of the tonus theory is that constant discharge of minimal quantities of adrenalin is necessary for the maintenance of sympathetic irritability. Direct experimentation in the writer's laboratory, however, showed that the injection of small quantities of adrenalin over a considerable period of time results, not in facilitating sympathetic reactions to stimuli, but often in materially impeding them.

Another theory as to the normal function of adrenalin can be deduced from the fact that in very minute quantities it augments basal metabolism. The disproportion between the quantity involved and the effect produced as well as direct experimentation indicates that adrenalin serves to catalyze some reaction in the process of fuel oxidation. It is probable that the intervention is in the immediate oxidation reactions, that is, that the substance serves as a respiratory catalyst.

Possibly related to the catalytic theory is the statement agreed upon by most investigators—Stewart and Rogoff dissenting—that the adrenals play an important rôle in resistance to fatigue. Mauerhofer has recently reported, for example, that rats surviving double adrenal extirpation and meeting ordinary conditions of life in an apparently normal way are very susceptible to fatigue and usually die after enforced activity. Hartman for the past two or three years has been studying the relation of adrenal discharge to muscular efficiency in cats working in a revolving cage. In his most convincing experiments the pupil on one side is completely denervated and by its dilatation serves as a signal when adrenalin is being discharged. Briefly, Hartman has found that often when the animal at enforced labor begins to show signs of distress the denervated pupil suddenly flares out and the cat simultaneously acquires "second wind." It is suggested that the warming up of athletes is partly a matter of arousing enough stimuli to initiate adrenal discharge. In other experiments the adrenal glands were removed or denervated, either of which procedures prevents any detectable discharge of adrenalin. Such cats were then fatigued to the point of distress and adrenalin artificially administered. In many instances this was shown materially to improve performance.

One other theory of adrenal function, though involving the cortex rather than the medulla, has long persisted, namely, that the gland is an important detoxicating mechanism. There are on record many observations indicating that the adrenal glands undergo degenerative changes after the administration of poisons.

Following the profound toxemia resulting from severe burns, adrenal destruction has often been reported as extensive. Moreover, animals, especially rats, that survive adrenal extirpation and remain in apparently good health show increased sensitiveness to a variety of poisons such as curare, cobra venom, morphine and diphtheria toxin (Lewis), whereas injections of adrenal extracts (whole gland) are reported to protect the animal from simultaneously injected toxins.

In view of the fact that adrenalin in relatively large doses produces marked hyperglycemia a theory that the suprarenals play an important rôle in the pathogenesis of diabetes mellitus has had considerable currency. Recent evidence, however, convincingly opposes this theory. Houssay, and more recently Stewart and Rogoff, have found that dogs deprived of the adrenal medulla and of most of the cortex develop characteristic diabetes after pancreatectomy, just as do normal dogs.

The Pancreas

A fascinating chapter in endocrinology has recently been unfolded as a result of the epoch-making studies on the pancreas. It is a matter for congratulation that we are to hear to-day an account of these studies from one who has had a large part in them.

The Sex Glands

Just now the sex glands are coming in for a great deal of attention, much of which could be gladly spared. There is a real danger that in the natural revulsion from prurient exploitation important experimental accomplishments may fail of due consideration. Through the results of centuries of experience the effects of gonad deficiencies in man and in the domestic animals are well known. It was not until recently, however, that it began to be understood that results of castration are due to resulting endocrine deficiencies.

Although not admitted by all students, the conclusion is almost assured that the hormone of the male gonads is formed in the interstitial cells of Leydig. The reproductive cells can be destroyed by x-rays without any detectable influence on the sexual habitus or psychology, a fact that should be of great interest to practical eugenists who are concerned with the problem of propagation of the unfit. Occasionally an individual is found to have sex glands in which no generative elements are found, but, if the interstitial cells are present, this subject also appears normal. On the other hand, if the gonads containing only interstitial cells and the connective elements are extirpated, the symptoms of castration promptly appear. If the operation is done before puberty, the subject remains sexually infantile throughout life. If done in the postpuberal period, there is a regression of the secondary sex characters to the

infantile condition. Not only, however, are the sex organs affected, but also changes are noted in the functions of the nervous system and in the psychology of the subject. A method recently described by Sand would seem to render easily possible final proof as to the rôle of the interstitial cells. This investigator reports that if the testes are transposed to an intra-abdominal situs the generative elements soon disappear, leaving only supportive and interstitial cells. Under such conditions he states that normal sexual development and reactions are maintained.

Some years ago Steinach reported a series of experiments, demonstrating the incretory functions of the gonads. A young male guinea pig was castrated and allowed to come to maturity. It remained sexually neutral. Similarly, a female from which the ovaries were taken remained in a neutral condition. If, however, into a spayed female the testes of a brother were grafted, the subject then developed various male attributes. The bones showed masculine characteristics in form and size, the hair became coarse and the subject inclined to dalliance with normal females. If the conditions were reversed, ovaries from the female being grafted into a castrated brother, this subject showed female development, the mammary glands hypertrophied and the animal was wooed by normal males. The work has been confirmed by Lipschütz in Dorpat, Sand in Denmark and Moore in this country. Thus the important fact appears to be established that in some experimental animals, at least, very striking transformations toward either the feminine or the masculine type can be induced by gland grafting. Steinach reported that he was unable to produce hermaphrodites, but Moore and Sand have succeeded in the endeavor, the individual having both viable ovary and testicle gland elements, and showing mixed male and female characteristics.

Recently Steinach has been working along somewhat different lines. With care to avoid injury of blood vessels, the efferent ducts of the testes are ligated. Following this, a marked degeneration of the sexual cells takes place. Steinach's theory is that the nutrition of the gland is then all thrown to the interstitial cells, which thereupon form an augmented amount of their characteristic hormone. The subjects are reported both by Steinach and by Sand to show varying degrees of rejuvenation. To what extent the effects are subjective is, of course, difficult to determine. Sand, however, has reported a ligation experiment in a dog showing marked evidence of senility. After the operation the animal became much more active, its nutrition improved and it took up as a favorite diversion accompanying its master on bicycle rides. In this case, suggestion could hardly have played a part; but we should not forget the long arm of coincidence.

At least brief mention should be made of Lilly's studies on freemartins. It has long been known that the female of bisexual twins in cattle is often sterile and develops various masculine characteristics. This is plausibly explained by the fact that the fetuses have an intercommunicating blood stream in which the hormones of the male twin could gain access to the body of the sister. It is supposed that under these conditions some preponderating male hormone, presumably from the gonads, suppresses the influence of femininizing factors.

As regards the female gonads, the source and nature of their hormones has recently been illuminated by the work of Loeb, Allen and Doisy, and Evans and Long. Although previous evidence permitted a somewhat plausible deduction that the follicular fluid contains an active substance, final convincing proof has but recently been offered by Allen and Doisy. Using rodents as experimental animals, these investigators have shown that the injection of follicular fluid results in striking sex stimulation. By relatively simple means a partially purified, highly potent extract has been obtained. From one to three injections of this extract into spayed animals produced typical estrual hyperemia, growth and hypersecretion in the genital tract as well as growth of the mammary glands. The spayed females exhibited typical mating instincts, taking the initiative in courtship and accepting congress with the male. Several injections of active extract were made into animals immediately after weaning, at an age of from three to four weeks. They became sexually active in from two to four days and from twenty to forty days before their normal litter mates. It would seem that this follicular hormone is the source of the stimulation whereby the estrual and presumably the menstrual cycle is maintained.

That the estrus is held in abeyance during pregnancy is well known. That the inhibitory influence emanates from the corpus luteum was a plausible deduction. The careful studies of Loeb have gone far to prove its correctness. Long and Evans have recently reported that in female rats treated with anterior lobe hypophysis extracts estrus is depressed or entirely inhibited. The ovaries of these animals are approximately twice the normal size, the added bulk being made up of persistent corpora lutea. In these cases, along with depressed estrus, uterine hypoplasia is noted.

Almost simultaneously there have appeared three developments in the field of endocrinology that may take preeminent rank. These are the isolation of insulin, of the growth-promoting substance of the hypophysis and of the sex-stimulating substance of the ovary. These discoveries are of first-rate importance not only on account of their immediate obvious significance but as affording means for

the attack of numerous difficult problems of far-reaching importance.

That the difficulties in the way of endocrine research have often been underestimated and that the literature contains a deplorably high proportion of immature contributions—or worse—is a regrettable fact. The widespread skepticism regarding endocrinology, or, at any rate, of much that seeks credit as endocrinology, is no doubt a manifestation of good scientific common sense. Despite the sins committed in its name, however, endocrinology constitutes one of the major developments in modern biology. While the subject demands rigid but open-minded skepticism, it would be deplorable if carping distrust or over-emphasis of its inherent difficulties should discourage investigation.

The field bristles with important problems at every turn. Indeed, some of the most elementary facts remain yet to be determined. What is a normal human thyroid? A normal adrenal? No one exactly knows. There is need of many exacting studies of the architecture and quantitative make-up of the incretory glands such as Hammar has made of the thymus and Rasmussen of the hypophysis. What part do the hormones play in determining the constitutional make-up of individuals, the establishment of family or racial characteristics? Keith, Pende and other writers have speculated engagingly upon this problem, but clean-cut evidence is notably lacking. This problem demands extensive and intensive investigation. What part do endocrine factors play in the onset of old age? That the body cells are potentially immortal seems sufficiently established. Death is but the last stage of stable, cellular equilibrium. Hormones are known to exert a profound influence upon cellular functions. That a detailed knowledge of endocrinology might double the allotted threescore years and ten of human existence is by no means a fantastic dream. What part do the incretory organs play in adaptation? This question epitomizes a hundred important problems that are crying for solution.

The field is wide. In no field of biology is the path of the investigator beset with more pitfalls and dangers. That the difficulties are becoming widely appreciated is an encouraging sign. Endocrinology offers no easy path to fame, but to the man who is willing to pay the price of patient, exacting work the field beckons enticingly.

THE DEVELOPMENT OF ASYMMETRY[1]

By Professor T. H. MORGAN

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It has been shown that the median plane of symmetry of the embryo, when not impressed on the egg by its stiff enveloping membrane, may in certain cases be traced back to another external agent, such as the path of entrance of the spermatozoon, or possibly, in one case, to pressure acting on the egg in the oviduct. It was not found necessary, therefore, to assume that a bilateral structure is present in the protoplasm of the unfertilized egg, as long as its origin could be explained as arising from extraneous sources. There is another group of cases in which structures that are asymmetrical develop. It is as important to discover the origin of asymmetry as to find out how a bilateral symmetry arises in the egg, and the situation is all the more interesting because the asymmetry is generally imposed on forms that have a fundamental, structural bilaterality.

The Asymmetry of Flat-fish

While most fish keep the dorsal side uppermost, flounders and soles lie on the bottom of the sea on one side. The anterior end of the body in particular is very asymmetrical. Both eyes lie on the side that is uppermost. The change in position in one eye is paralleled by extensive changes in the shape and arrangement of the bones of the head. Other organs than the head are also much affected; in fact, evidences of asymmetry may be found throughout the entire body. Yet the young flounder is, at first, like other fish. It has a bilateral form and swims with its dorsal surface uppermost. When a certain stage is reached, the young fish sinks to the bottom, but even before doing so the changes that lead to its later asymmetry have begun to appear.

Some species lie on the right side (summer flounder), others on the left (the halibut). Rarely a flounder is caught that is "reversed." These may seem to indicate that at the beginning both sides have the same potentiality. Such a view, if true, would still leave unexplained why certain species, with the rarest exceptions, turn on to a definite side—right or left, as the case may be.

The changes that take place when the asymmetry appears have been examined by several embryologists, Pfeffer ('86), Williams ('02), Mayhoff ('14), but the fullest account is that of Kyle ('21) who finds the earliest evidence of asymmetry in the twisting of the

[1] Chapters from Experimental Embryology. III.

gut, and in the position of the swim bladder and other visceral organs. The twist gradually extends forward as the embryo turns to one side, and finally the head becomes involved. Kyle points out that in the earliest stages the asymmetries are not unlike those found in other fishes, but in these a compensation takes place enabling them to retain a dorso-ventral position. In the flat-fishes the changes progress until the effects are far-reaching. Kyle seems inclined to think that these changes in the young fish have forced the flat-fishes to adopt a bottom life, rather than that the adult stage is an adaptation that has, so to speak, affected the younger stages in the course of evolution. If the changes are germinal to-day, we must suppose that they have always arisen in this way, although not all at the same historic moment unless one adopts the view of the inheritance of acquired characters. In other words, it is not improbable that the conditions seen in the flat-fishes to-day have gradually resulted from alterations of the germinal material of such a kind that in the course of time the asymmetry has become more perfect so that now the fish are better adapted to a bottom life. Kyle thinks that the flat-fishes are polyphyletic in origin, *i.e.*, this kind of change has occurred independently in at least four groups of marine fishes. Such a view, he states, is supported not only by comparative anatomy, as others had already pointed out, but also by the evidence from embryology, indicating that in each group the changes have taken a somewhat different course.

The most remarkable alterations are those involving the bones of the head, but these changes are always preceded by earlier ones in the head and body. In the skull the changes are "obviously due to pressure or stresses; apart from the tendency to grow, the structures are quite passive. The eye is not pulled into its new position by the frontals or its own muscles; it is demonstrably pushed over by the growth of the subocular ligament or the prefrontal. These, again, are constrained to grow obliquely by outside pressure. When rupture of the tissue is apparent, it is not due simply to the structures growing apart; they are definitely forced apart." Sinistral forms have almost invariably an air bladder lying more or less on the right side. Dextral forms have either no air bladder, or the air bladder more or less on the left side. "Throughout development, variations in the rate of metamorphosis can be judged by differences in the balancing conditions of the abdominal region."

Aside from the experiment of Cunningham ('91) on the effect of illuminating young flat-fish from below that had already turned to one side there is as yet no experimental work on these fish that bears on the question of their turning. In another group, however, the Amphibia, the asymmetry of the heart and digestive tract has been traced to a very early stage. There is also experimental work

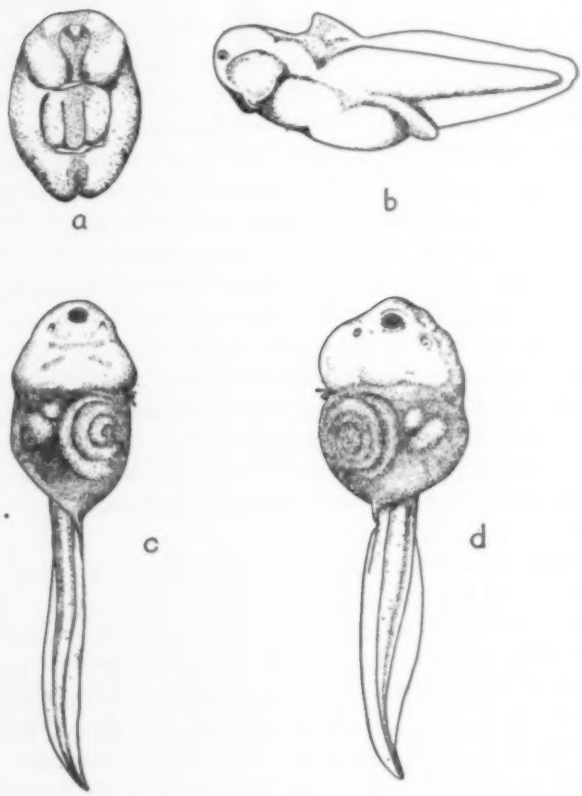


FIG. 1

that promises to throw some light on extraneous conditions that may influence the direction of the twisting.

THE ARTIFICIAL PRODUCTION OF SITUS INVERSUS VISCERUM

Spemann ('06) discovered that if a square piece of the neural plate of the embryo of the frog is cut out and is then turned around through 180° and replaced (Fig. 1, a), the position (situs) of the digestive tract (Fig. 1, c, d) and of the heart may be "reversed." Such a result was unexpected, since only a dorsal piece of the digestive tract was reversed, while the heart lies on the ventral side of the body. The result might be accounted for if the reversion of the digestive tract is first determined by the reversion of the dorsal piece and this influence affects secondarily the position of the heart. Spemann suggested, in fact, that the asymmetrical position of the liver, that arises at an early stage from the ventral wall of the digestive tract, might influence the direction of the blood that enters the posterior end of the heart in such a way that the direc-

tion of its twisting is affected. If the position of the liver is changed by the operation, the blood current might also be changed and bring about a reversal of the twisting of the heart tube.

The material collected by Spemann was turned over to one of his students, Pressler ('11), for further study. There were 19 operated embryos, three of *Rana esculenta* and sixteen of *Bombinator igneus*, the latter giving a tolerably complete series of stages. In order to determine what condition underlies the normal position of the viscera (situs viscerum) young stages were examined in serial sections. The first appearance of asymmetry is found in a stage where the digestive tract is still a straight tube. On its ventral wall, where its wide pharynx cavity narrows to become the oesophagus, an outpushing marks the beginning of the liver. Just in front of this, under the lower wall of the pharynx, the beginning of the heart appears (Fig. 2, a). At this time it consists of a straight endothelial tube lying between walls of mesoderm that have opened out, right and left, to mark the beginning of the pericardium.

The liver rudiment projects a little to the right side of the middle line, and lies just behind the heart (Fig. 2, c). The intestine turns a little to the left side. The two large yolk-veins that open into the posterior end of the heart are present at an early stage. They are developing, in fact, while the changes outlined above have been going on. The left vein is larger than the right (Fig. 2, a), the smaller size of the latter being due, possibly, to the diminished space on the right side where the liver is pushing out. The pericardial cavities are also at this time a little asymmetrical. The right is slightly smaller than the left (Fig. 2, a). The mesocardium turns above and anteriorly to the right, behind and below to the left. This leads to, or is involved in, the slight bending of the endothelial tube leading through an S-shaped course to the anticlockwise spiral of the heart tube.

The embryos that develop after the operation (*i.e.*, after the reversal of the dorsal piece) show the following conditions. The dorsal fin does not gradually increase in height from its anterior end

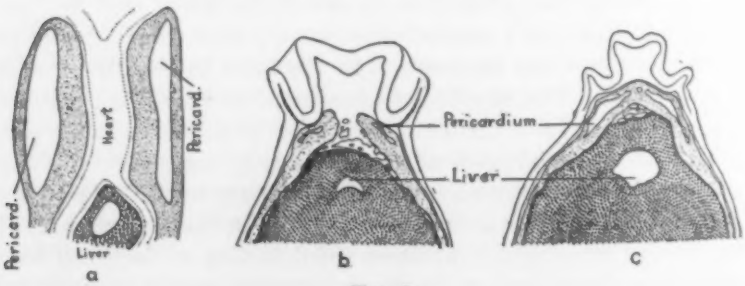


FIG. 2

to the tail as in the normal tadpole, but is broken in its course (Fig. 1, b), being higher at the anterior end of the transposed piece and lower at the posterior end where it joins abruptly the higher fin behind. Evidently the fin has developed as though still in its normal position. Similarly, the medulla and the chorda of the transposed piece, although continuous with the medulla and chorda of the embryo, change in size abruptly at the anterior and posterior levels of union.

The operation removed only the roof of the archenteron. The portion removed includes the part that becomes the dorsal wall of the foregut (duodenum) and the first part of the midgut and may include the region from which the dorsal pancreas is given off. This portion of the gut is then inverted, that is, it is expected to take the opposite turning from that taken by the normal embryo. This initial inversion in the anterior region may be expected to extend backwards throughout the rest of the digestive tract, into regions lying posterior to the inverted piece, provided its course is determined by changes that start in the more anterior region. In the operated embryo the liver pushes over to the left, instead of to the right, in the earliest stages observed, although its material lay far below the level of the operation. The dorsal and ventral pancreas unite, not on the right side, but on the left. In all Pressler's 15 cases, where situs inversus viscerum is present, the heart is inverted and this can be traced to its earliest stages. The right yolk vein is larger than the left and the heart bends to the left instead of to the right. Its spiral takes a clockwise turn. The inversion present involves even the finest details of structure, and, since the heart lies beyond the field of operation, its inversion must be supposed to be induced by changes that first occur in the region of the liver. Since one of the yolk-veins is smaller than the other, Pressler suggests that the consequent change in the direction of the blood flow may be the immediate cause of the inversion of the heart.

Several years later ('13) another student, Meyer, working with Spemann, made a larger number of operations of this kind. He examined in more detail the very early stages of the normal asymmetry and has made out a few further significant relations. His general conclusions also differ to some extent from those of Spemann and of Pressler. Meyer obtained eight cases of inversion (out of 9 operations) in Bombinator; 16 cases (out of 19) of *Rana esculenta*, and 6 of Bufo.

A study of the normal conditions in young embryos at a time when the first asymmetry could be detected showed that at the stage when the liver begins to turn a little to the right, the visceral sheet of mesoderm on each side of the endothelial tube of the heart shows also a slight asymmetry (Fig. 2, c). On the right side there is a

slight bend in the visceral sheet, while on the left side it takes a straighter course. The slight bend in the right side corresponds with the later bending of the S-shaped tube and beyond doubt is the first indication of future relations.

In these earliest stages the yolk-veins have scarcely formed and are not yet hollow vessels carrying the blood as they are a little later, and since at this stage there is no blood circulation, it appears probable that the bending of the heart tube can not primarily be due to the greater flow of blood from one of the yolk-veins.

Meyer found in the operated embryos (with an inverted neural plate) that the liver turns to the left and the relation of the right and left visceral layers is the reverse of that of the normal embryo (Fig. 2, b). These observations show that here also the asymmetry is very early initiated and is due most probably to the position of the liver. This, in turn, affects the visceral walls of mesoderm that extend over it and then forward to the heart region. It seems reasonable to infer that the differences seen in the two visceral layers, right and left, are initiated by the direction taken by the liver outgrowth.

Since at the time of the operation the mesoderm also extends under the neural plate and is inverted with the plate, it may appear possible that the mesoderm of the heart region may also be affected indirectly by this inversion. Such a view is rendered improbable by the fact that the dorsal inverted mesoderm lies behind the level of the future heart region, *i.e.*, it is not mesoderm lying on the dorsal side above the heart level.

Meyer attempted to find out by a critical experiment whether situs inversus is due to the inversion of the whole dorsal piece or only to the inversion of the dorsal wall of the archenteron. A square cut was made and then he attempted to lift off the neural plate (ectoderm) and the underlying mesoderm, leaving in place the dorsal wall of the archenteron. It was found impossible to leave the endoderm intact, but in some cases a large part of it (more or less torn) remained. The plate removed was then inverted and replanted in the opening. In five cases both digestive tract and heart were found to be inverted, possibly because enough endoderm had been left sticking to the inverted plate to cause inversion in the digestive tract. In three cases, on the other hand, no inversion took place, neither in the digestive tract nor in the heart, because possibly enough endoderm had been left to maintain the normal relations. The last result shows at least that the inversion is probably not caused by the action of the neural plate. It may be added that both Spemann and Meyer found that if the square plate after being cut out was not replaced, but the opening was allowed to close, no inversion took place.

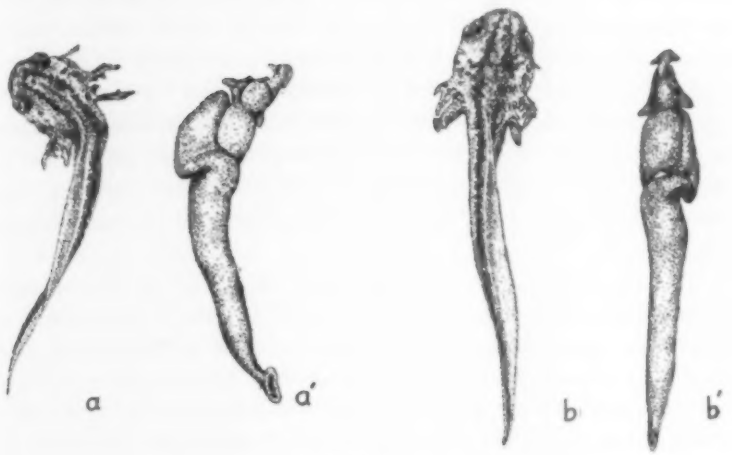


FIG. 3

The influence of the inversion on the position of the spiraculum was also examined by Meyer. In Bombinator it is ventral and median; in Rana and Bufo it lies in the left side. Spemann found that in one case the spiraculum was inverted when situs inversus was induced. In two other cases it did not unite across the middle line. Meyer found in five cases of situs inversus in *Rana esculenta* that the spiraculum opened on the right side (Fig. 1, d). This occurred also in one larva of Bufo.

There were a few cases in which inversion of the digestive tract was present, but the heart was not inverted. Such cases may possibly be due to the normal position of the heart having been already determined before the time of operation, so that while the inverted plate acted on the digestive tract, the heart continued to develop in response to the earlier influence of the normal relations.[2]

In this connection some experiments of a very different kind should be described that also bring about inversion of the digestive tract and heart. These results were obtained first by Spemann and later by Spemann and Falkenberg.

When a ligature is placed around the egg of Triton in the plane of the second cleavage and is then subsequently tightened so that the egg is constricted into two parts, either two whole embryos are obtained, right and left (Fig. 3, a, b), or one embryo with a double

[2] Mangold ('21) has shown that situs inversus occurs normally, *i.e.*, without operation, in about 2 per cent. of the larvae of *Triton taeniatus* and in nearly the same ratio in *T. alpestris*. When, in these, the heart is inverted the intestine is always inverted, but the liver or the intestine may be inverted and not the heart. Wilhelmi ('21) brought about inversion by removing a part of the left posterior side of an embryo when the neural fold was about to develop (one case in five).

anterior end (Fig. 4). When two embryos develop one or both are often defective especially on the "inner" side, but the results in regard to inversion seem to bear no direct relation to the extent of the abnormality. In 25 sinistral larvae both the heart and the digestive tract have a normal orientation. Only in one is the heart inverted while the condition of the digestive tract is uncertain. In 30 dextral larvae the inversion of the heart and digestive tract was clearly present in 12 embryos and probably in 2 others; the rest were normal.

Two other pairs may be added to the above list in both of which the sinistral embryo is normal, the right inverted. Other cases in which the halves remain partly united show sometimes the same relations. In 12 cases the left component was normal; the right, anterior region of the digestive tract was normal in only two cases; in the remaining 10 embryos the anterior part was inverted.

These results show that the inversion, when it occurs, is in the right-hand member of the pair. The cause of this is not evident. It does not seem connected with the incomplete development of the "inner" side that is shown by many of these larvae. Defects may be found in the eye or ear or in the musculature, or a limb may be absent on the inner side. If this one-sided condition prevails to some extent in the digestive tract and if the liver projects more to the more complete side (*i.e.*, away from the "inner" side) then this would be the normal direction for the right side, since normally the liver pushes more to the right, but it is these right larvae that show the inversion. The left larvae would be the ones expected to be inverted, but this is not the case. The explanation is contradictory to the facts.

FIG. 4

Spemann inclined to refer the asymmetries of the normal embryo either to a primary micro-structure of the egg, or to some asymmetrical action of the sperm on the egg. But even on such an assumption it must be conceded that this "fundamental" structure can be readily inverted, as shown by the experiments. Since the double embryos are, when inversion occurs, mirror figures of each other and since this relation is not an uncommon accompaniment of paired whole structures, it might seem promising to refer the result to this general category, even although there is at present no adequate causal explanation of the mirror figure relation. But in the separated embryos the mirroring takes place when the parts are entirely separated. I am inclined to look, therefore, to some secondary condition imposed on the two embryos as a result of the deficiency on their inner side—a condition that supplements the initial steps already present in the left embryo, but which acts inversely on the conditions of the right embryo. For example, if the digestive tract and liver of the left embryo are displaced somewhat to the right (the inner or defective side) such a change is in the direction taken by the liver in the normal embryo and no inversion is expected. In the right embryo, a similar shift will displace the digestive tract and liver to the left (the inner or defective side) and such a change is in the opposite direction to that taken by the liver in the normal embryo and an inversion might result.

Other Cases of Inversion

The preceding cases, in which two embryos were obtained from a single egg, recall the double embryos (double monsters) that sometimes are found on the same egg. This is not an uncommon occurrence in fish embryos. In some of these cases it has been found, in fact, that the heart and digestive tract are often reversed in one of the embryos (Morrill '19, Swett '21). How far this result is due to the degree of separation of the two embryos and how far to a mutual influence of one on the other of such a sort that they become mirror figures of each other, as in cases of reduplicated limbs, will be considered in another connection.

The asymmetry of the aortic arch in birds and in mammals is another instance of asymmetry superimposed on a fundamental symmetry. The suppression of the right ovary and oviduct in birds may be connected with the turning of the embryo onto its left side at any early stage, but this relation has not been established, although it might easily be tested in those not infrequent cases where the chick lies on its right side. Dareste (1877) produced situs inversus in chicks by heating the left side of the egg (embryo) more than the right. The result has been confirmed later by Warynski and Fol ('84).

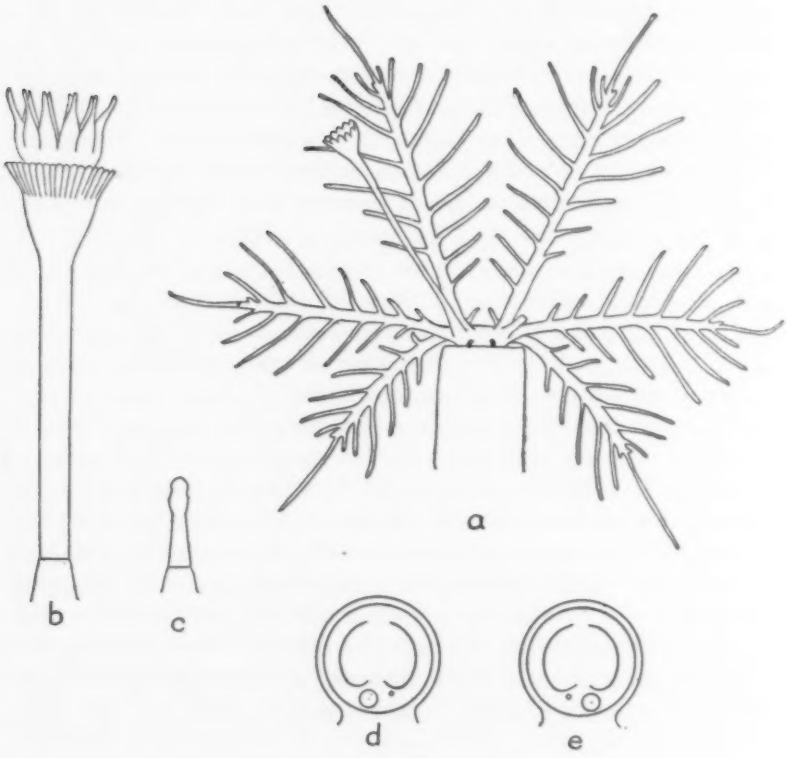


FIG. 5

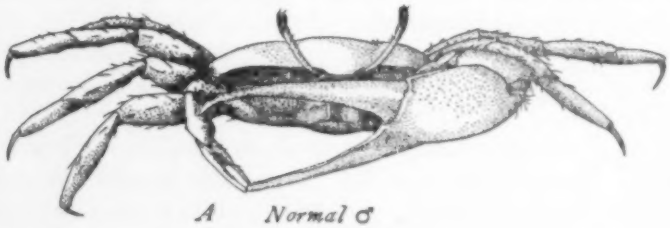
A few instances of situs inversus have been observed in larval sea urchins (Runnström '12, Ohshima '22) and in starfishes (Müller '50, Masterman '02, Mortensen '21). The pluteus stage of a sea urchin is normally asymmetrical; a functional hydrocoel being present only on the left side. In the reversed pluteus it lies on the right side. Several instances have also been described both in larval sea urchins and in starfish (Newman '23) where both a left and a right hydrocoel are present. Such larvae are symmetrical, standing as it were midway between the normal and the reversed condition.

The thread worm of the horse, whose eggs have a determinate and symmetrical type of cleavage, shows distinct asymmetries in the nervous system and in the excretory vessels of the adult, and these are typically on the same side. Zur Strassen found that about one egg in 40 has "inverse" cleavage, and that four adults out of 125 showed reversal. It seems plausible, as he points out, to assume that the reversed cleavage type gives rise to the reversed adult type.

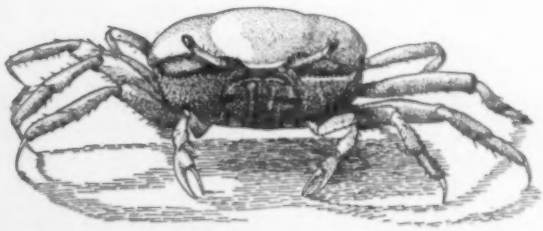
THE ORIGIN OF ASYMMETRY IN SERPULIDS AND FIDDLER CRABS

Some of the sedentary annelids, such as Serpula and Hydroides, have a sort of plug (operculum) that closes the tube when the worm retreats into it. The plug arises from one side of the middle line (Fig. 5, b). On the opposite side there is a tiny rudimentary plug (Fig. 5, c). Both represent modified gills of the young embryo (Fig. 5, a). Zeleny ('02, '04) has shown that if the large plug of the adult worm is cut off, the smaller one begins to grow, and in the course of a few weeks becomes as large as the one removed, and acts as the functional plug. From the stump of the original large plug a new, small plug develops. If now this secondary functioning plug is removed, the secondary small one enlarges to full size, and from the stump a small one develops, etc. This evidence indicates that the presence of one functional operculum holds its mate in check. The nature of this influence is not known. One is tempted to refer it to some material produced by the more developed plug that holds the other in check or by something used up by the larger plug that the smaller one needs to develop. Both of these views may, however, seem self-contradictory, since the influence imagined would be supposed to act in the embryo on both alike unless a threshold value is assumed. Since either the right or the left may be the functional plug, it would then appear to be only a question of chance which one got the start of the other. Such an interpretation would call for no contrivance in the egg to throw the balance to one side or the other.

The first pair of legs bearing the large "claws," of many crabs,



A Normal ♂



B Normal ♀

FIG. 6

FIG. 7

lobsters and other crustacea are different on the two sides and markedly so in the male fiddler crab (Fig. 6, A) and in the macruran alpheus. Here the larger claw may be either the right or the left one. There is no predetermined asymmetry. Once determined, however, it may be made to reverse in some species but not in others. As shown by Przibram, removal of the large claw of Alpheus leads, at the next molt, to its substitution by the smaller claw on the other side; but in other decapods, as in the fiddler crab, the large claw of the adult, if removed, develops again, and is not substituted for by the claw on the other side.

The development of asymmetry in the male fiddler crab (Gelasimus) has recently been worked out by Morgan ('21, '22, '23). In the youngest stages the two claws are alike in the male and female. In a later stage of the male both claws become a little larger than those of the female of the same age and show the swollen shape of the male "large" claw (Fig. 7, A). At about this time most of the young crabs lose one or the other of these "large" claws and produce at the next molt, in place of the one lost, a small claw like that of the small male claw or like the two small claws of the female (Fig. 7, B). This relation, once attained, becomes fixed, and even in young crabs no reversal after the removal of the large claw is possible. An accident, then, determines in this crab the first asymmetry of the claws of the male. There seems to be nothing in the egg or in the development that brings about the asymmetry. It is determined by an asymmetry traceable to an accident.

If the young male with two large claws is isolated and carefully protected from injury and fed, he usually retains both claws throughout successive moults and develops into a symmetrical male with two large claws. There are only two records of such adults found in nature, and since this occurrence is extremely rare, it might be expected that the loss of one claw, even at a somewhat later stage than that at which the loss normally occurs, is the event that generally leads to the asymmetry of the adult. In fact, experiments with very young males, that have retained both claws through two or more moults later than the moult at which the loss usually occurs, show that a small claw develops in place of the large one removed.

The converse experiment has also been carried out. Both claws were removed from young males with two large claws. At the next moult two small claws developed and in the two or three subsequent

moults both claws remained small. If this condition persists into the adult stage, a symmetrical male would develop with two small claws. A few such adult males have, in fact, been found (Morgan '22).

In a few cases where two secondary small claws were induced, as just described, one small claw was then removed. A small claw came back and the opposite claw also remained small. The induced symmetry has inhibited the individual from acquiring the normal asymmetry. In other words, when at the critical stage the individual has been led to take a false step, no subsequent rectification is possible.

Here, then, esymmetry is introduced, as a rule, relatively late in development. There is nothing in the egg responsible for the asymmetry unless it be the reaction system that responds at a cer-

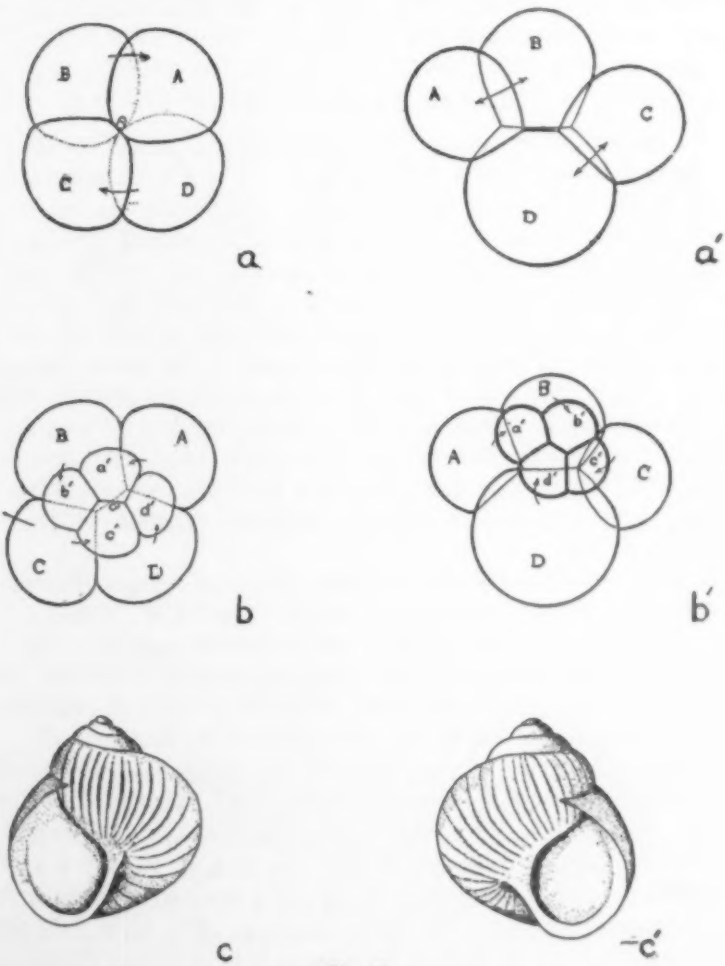


FIG. 8

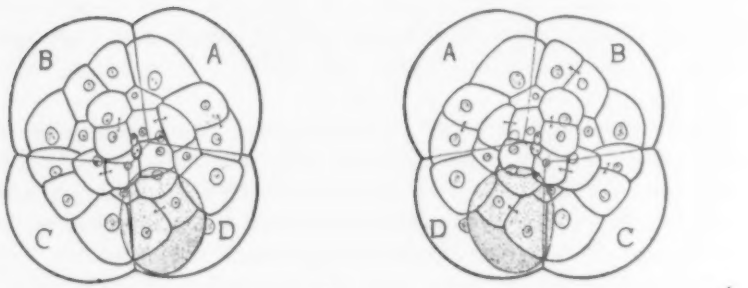


FIG. 9

tain stage in the development to an induced asymmetry. If in the young male crabs the right claw is lost as often as the left we can understand how it comes about that half the adult males have the right claw large and half the left claw.

THE ASYMMETRY OF SNAILS

In gasteropod molluscs the visceral mass on which the shell is moulded is twisted into a right- (Fig. 8, c′) or a left-handed spiral (Fig. 8, c). In some species, the spiral is typically dextral (Limnaea and Crepidula); in other species it is sinistral (Physa and Planorbis). Even within the same species there may be dextral and sinistral individuals. For example, some species of the Achatinellidae are typically right-wound (dextral), others left-wound (sinistral), but in some species both dextral and sinistral snails are found (Mayer '02, Gulick '05). Similar conditions are also found in Tahitian snails (Crampton '16). In several dextral land snails of Europe sinistral individuals have been frequently described (Lang '08, Hesse '14) and in certain localities reversed forms of several fresh water snails have been recorded (Dewitz '16, Boycott and Diver '23).

Crampton ('94) pointed out that the spiral type of cleavage is reversed in dextral and sinistral snails (Figs. 8, a′, b′ and a, b). In consequence of this relation, the mesoderm cell, 4d (Fig. 9), that is generally larger than the other members of the fourth quartet (4a, 4b, 4c), lies to the right of the first plane of cleavage in one type and to the left in the other (Fig. 9, the stippled cell).

The asymmetry has been traced to the position of the spindles for the second division of the egg (Crampton). It is further shown by the "cross furrow" at the meeting point of two blastomeres of the four-cell stage (Fig. 10, b′ b). As seen in Figs. 8 a and a′ the cross-furrow in the sinistral type (a) is the mirror figure of that in the dextral type (a′). In the dextral type (Fig. 10, a′), the right end of the spindle in the AB blastomere is higher than the left end

of the same spindle; and *vice versa* for the spindle in the DC blastomere. Since all later cleavage alternates between dextral and sinistral, Conklin ('07) suggests that even the first spindle may be dextral in the dextral type and sinistral in the sinistral type of cleavage. This has, however, not been demonstrated, although it seems quite probable.

At the third division of the egg four small cells are pinched off around the pole of the egg by a clockwise division in the dextral type (Fig. 8 b′) and by an anticlockwise division in the sinistral type (Fig. 8b). After this division a succession of small cells are formed from the four large cells (ABCD) by alternate anticlockwise and clockwise divisions. This continues until, at the seventh division, a large cell (4D) is pinched off from the large D-cell (Fig. 9). This cell, as stated above, is the first asymmetrical division in the sense that this cell (4D) is sometimes given off sooner and is often much larger than the corresponding cells of the other quartets. This 4d cell lies on the posterior side of the embryo and in the dextral type to the left of the middle line (Fig. 9, b)

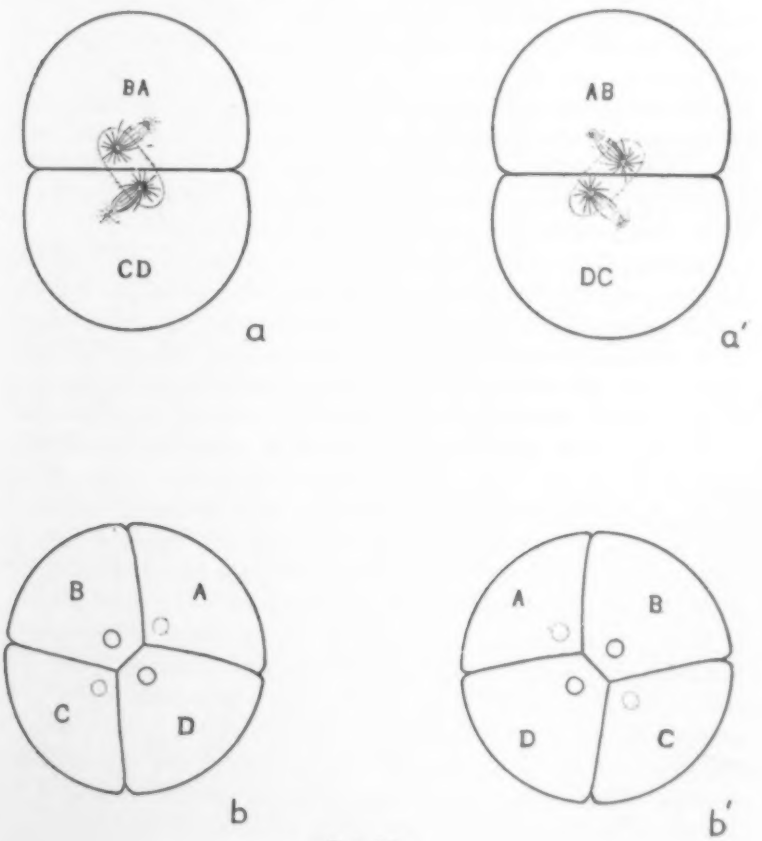


FIG. 10

which corresponds nearly to the second plane of cleavage. In the sinistral type the 4d cell lies to the right of the middle line (Fig. 9, a). The asymmetrical position of this cell from which the middle layer of the embryo arises suggests that the later asymmetry of the body is built up on this relation. On the other hand, the position of 4d may only be an expression of the type of cleavage and the latter rather than 4d itself may be the forerunner of the asymmetrical structure that develops.

Several attempts have been made to explain the spiral type of cleavage of the molluscan egg as well as the origin of the reversals seen in certain cases. Rabl ('00) called attention to spiral asters in certain eggs described by Mark ('81) and by Kostanecki ('96). He suggested that these spirals might indicate a spiral foundation in the cytoplasm responsible for the spiral cleavage, but later research has not confirmed these earlier observations as typical. In fact, the spiral aster is probably an artifact (Byrnes '99).

Conklin pointed out that if in snails having the right-handed spiral type the polar bodies are formed at the pole of the egg and the quartets are formed about the same pole, and if in the left-handed species the polar bodies are given off at the antipole and the quartets are also formed at the antipole, then the two types would show reversed spirals if these depended on the same fundamental spiral structure in the cytoplasm. Conklin has himself called attention to the difficulties in making such an interpretation, and there is no evidence that the poles are reversed in the two types of eggs, and much evidence that they are not.

Holmes ('00) suggested that if the first cleavage of the dextral form corresponds to the second cleavage of the sinistral types this would account for the reversal of the spirals. At present there is no evidence of such substitution. The only advantage that such a view might offer would be that the spiral structure of the protoplasm, if such exists, might be assumed to be the same in both forms.

It may seem hazardous, in the light of these difficulties, to attempt at present to suggest a solution of the two types of spiral cleavages leading to the final asymmetry of the snail, were it not that in one respect at least we have recently made a step forward. The genetic evidence indicates that the twisting is inherited as a Mendelian character, and is, furthermore, a special case of maternal inheritance; it follows that the character is impressed on the ovarian egg before the polar bodies are extruded. Two possibilities are then given; either the influence is exerted from the egg-nucleus before its maturation divisions, or else it is determined by the follicle cells of the mother that surround the egg during its growth. The former alternative offers no further clue as to how the cytoplasm is affected; the latter alternative might appear to offer a solution. For example, if the polar region of the egg were

supposed to be oval in shape (as a result of the influence of the follicle) and if in the dextral type the oval is turned to the right (Fig. 10 a′) and in the sinistral type to the left (Fig. 10), and if the position of the two spindles at the second division is determined by this polar field then it might appear that the differences in the two types could be accounted for.

On the other hand, there are some obvious difficulties for this interpretation. It must be supposed, for instance, that in a snail that is actually sinistral (owing to its maternal inheritance) but genetically dextral, the latter influence, and not the form of the twist, determines the character of the egg. In the second place, it has been shown by Wilson ('04) in the mollusc Dentalium whose egg cleaves spirally, that fragments both of the upper and of the lower hemisphere cleave spirally in the same way as does the whole egg. Such a result is inconsistent with the assumption that the spiral is due to an influence starting during cleavage from the polar field. It might also be urged that the dextral type of cleavage is present in forms like Nereis that are themselves bilateral; but this is not perhaps a serious objection, since it is not the shape of the individual that determines the twist, by hypothesis, but the genetic make-up of its cells.

Under these circumstances it is apparent that the hypothesis suggested above is entirely inadequate. The situation, as it appears at present, may possibly be stated as follows:

(1) The genetic evidence indicates that the type of cleavage, dextral or sinistral, is inherited probably as a Mendelian pair of characters. Furthermore, the inheritance appears to belong to that category of cases known as maternal inheritance.

(2) Since the characteristic type of cleavage is shown by fragments taken from any region of the egg, it is not probable that it can be traced to any localized structure on or in the egg, but is a peculiarity that develops in the protoplasm at about the time of fertilization and need not be supposed to be present as such before this time.

(3) It is not necessary to assume that this peculiarity is expressed as a spiral structure in the protoplasm. There may well be other influences that turn the first spindle in an oblique position with respect to the primary axis and at the same time direct the spindle in the clockwise (or anticlockwise) direction. The later reversals of the cleavage may be due to the orderly sequence of the succession spindles at right angles to the last ones (or possibly also to the form of the preceding cells). This view avoids the difficulty of assuming that the influence, that gives the first spiral, reverses itself at each subsequent division.

We need at present critical experiments to test these and other

possibilities. By compressing the egg, by studying the cleavage of fragments of sinistral types, or by altering the conditions of the egg in other ways, it should be possible to discover the nature of the protoplasmic factors that determine the spiral cleavage pattern.

Finally, since the position of the first cleavage plane is not predetermined, either in the bilateral or in the spiral types, it follows that the median plane of the embryo may coincide with any meridian of the egg. Therefore, whatever the nature of the conditions that lead to a spiral cleavage they carry with them the condition that locates at the same time the bilaterality of the embryo. The two must, I think, be regarded as part of the same process.

THE NEED OF INTEGRATION OF ATTITUDES AMONG SCIENTISTS

By Professor KIMBALL YOUNG
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THE difficulty in getting the masses to understand and to react consistently to modern science seems to some disheartening. When educational and governmental experts, health boards and, in general, the applied technicians are handicapped in executing their programs to apply science among the masses, they wonder at the social inertia which they encounter. One must not overlook, however, the disconcerting fact that very often among scientists themselves is found the most curious mixture of modernism in a specialized field coupled with an intense adherence to some medieval or primitive superstititon which is unworthy of them. The inertia against change exists in us all, but if we can give men of science a training which, among themselves, will aid in producing an integration of attitudes towards the total contribution and cultural meaning of science, we shall have another force to strengthen our attack on ignorance, traditional taboos and pseudo-science with their attendant controls of the man in the street.

Before discussing the present education of the scientist and offering suggestions for improvement, it will be necessary to trace briefly the fundamental bases of personality upon which the integration of attitudes rest.

Beginning with the behavior of simple organisms and going up the biological scale to man himself, we find an increasingly complex integration of behavior patterns directing the action of the total-going organism. In man and the mammals, particularly, this reaches an exceptionally high level through the complex development of the brain cortex.

While synthesis of part-processes of activity into total behavior is common, there also lie in us the roots of dissociation of these part-processes from each other. In fact, the new conditioning which goes on in learning is partially a procedure which involves the disintegration of old habits and the formation of new. We all possess trends which lead to the development of antagonistic sets of attitudes and habits, quite as much as trends in the opposite direction. In certain skills, automatic writing and kindred phenomena are seen extreme features of what is common to all in minor ways. Furthermore, the same possibility of integration, or its opposite, lies in the realm of ideas as in that of motor responses. One

easily recalls persons whose attitudes are quite as dissociated as motor processes may be. These are the persons of "compartmentalized" types of conduct.

Dissociation tendencies arise from two principal factors, among others: (1) the nature of the individual's ideas and attitudes which rest, in part, upon his emotional-instinctive background, but which lie especially in the field of fundamental behavior patterns laid down in the early years of life, and (2) the diversity of stimuli, that is, the differences in environmental situations in which the personality grows up. It is obvious that the diversity of stimuli possible is correlated throughout development with the diversity of response-systems. The primary external stimuli to which the individual reacts and around which his "values" grow up are found in the family, the playground, the school, the gang, the church, the business and industrial groups, recreational situations, including responses of sexual nature and the very important group of objects and situations which involve sensory-perceptual explorations and manipulation.

The question, then, is how to integrate these conflicting trends into a working whole, not necessarily attempting to make the entire personality revolve around one small item, but correlating the various trends so that they operate in a harmonious synchrony for greater effectiveness and more complete response.[1]

The problem of the scientist is a part of this same cloth. It is frankly evident in the fact that the present-day man of science is, on the whole, unable or unwilling, because of paucity of training, to try to see his problem in perspective.

Science had its roots in philosophy, which for long periods remained under the dominance of the deductive rather than the inductive method. But even the older philosophy had the virtue of emphasizing the integration of knowledge and life activity. But much of what is now considered of greatest importance in science is the outcome of the empirical attack of men on specific phenomena which the older philosophy ignored. It is natural that modern science should more and more move away from the older philosophic position to one of individual studies upon isolated problems, correlating results and bringing in generalizations only as they seem apparent from the data.

[1] The integration of personality, the writer believes, is closely bound up with the notion of completeness of response in the organism. *Cf.* J. Peterson: "Completeness of response in learning," *Psych. Rev.*, 1916, XXIII, 153ff; also, his "The functioning of ideas in social groups," *ibid.*, 1918, XXV, 214ff. For the acceptance, in part, of this idea by certain philosophers, *cf.* R. B. Perry, "Docility and purpose," *ibid.*, 1918, XXV, 1ff., and E. B. Holt, "The Freudian Wish," 1918, especially "Appendix."

The individual, in reference to the presuppositions of modern science, can be described for our purpose under a doctrine of attitudes. The scientific frame of mind is nothing but a system of attitudes, ways of looking at phenomena, largely non-conscious in the adult worker and produced by years of training. That which distinguishes a scientist from the common man is not only the stock of information and technique which the former possesses, but quite equally the "mental set" through which the former looks upon the world. The recency of this scientific attitude is one of the significant facts in "intellectual history."[2] Even the average scientist does not realize the profundity of meaning science may have for future culture and conduct. It is the hope of the technician that the results of science may spread more and more into human life and behavior, replacing the superstitions, rationalizations and ignorant controls of the past for the predictable and ultimately humane controls of science and ethics. Science is man's contribution to himself, in contra-distinction to the benefits of nature. Whether the individual worker in science agrees or not, the broader view must realize that the applications of science should relate to social, that is, ethical ends. Whether but a part-process of science, as it were, and not its entirety be given to benefit man depends largely upon the integration of the scientific with the other attitudes:—moral, esthetic, religious, political and economic—resulting in a synthesis of the whole for social and individual enhancement.

The following not uncommon case will illustrate the general meaning here. The writer is acquainted with a brilliant natural scientist whose training was the best which this country affords. His doctor's thesis was considered an exceptional contribution and won him a *summa cum laude*, the first ever given by his particular department. His dissertation was translated into both German and French within a few months. This man is to-day employed in research of importance, and it is but a step from his own field to that of philosophy. Yet this specialist, in spite of his training and position in a highly technical field, is distinctly medieval in his attitudes on religion, political science, economics and biology. He gives aid and comfort to the sort of organizations which dismisses men from its educational institutions for belief in evolution, has himself been known to speak "with authority" against the theories of modern biology and to defend the most ultra-reactionary political movements. This is frankly an extreme instance. It illustrates, however, the problem under discussion. One does not expect any man to be an expert in every field. The point is more that this person, while

[2] *Cf.* James Harvey Robinson, "The humanizing of knowledge," *Science*, n. s., June 28, 1922, LVI, 89ff.; also, "The Mind in the Making," 1921.

possessing an important place in his own field, is lacking in that all-valuable matter of general perspective. Before expanding the implications of this type of mind, let us look at the present educational regimen to which the young man of ambition for science is subjected and at the arena of action, too, in which most scientific work is done.

At the outset it must be recognized that the recency of science has prevented its reaching into the earlier training of the average pupil. Our elementary schools are still proceeding in large measure upon the traditions of previous centuries both in method and material. The basic education of many present-day scientists was totally unsuited to their later work. Nevertheless, in the breaking up of the curricula into differentiated systems and, especially, in the project method of teaching, do we get glimmerings of what may become universal. The lamentable fact remains that the usual elementary and high school teacher is poorly prepared to give and encourage the scientific attitude and technique. Often enough the individual teacher has fairly adequate training in his special field, but lacks that important background which we shall indicate. Furthermore, the methods of presenting science in elementary and high schools are antiquated. The student is not invited to take the standpoint of a searcher after facts, but is taken on informational excursions into intellectual museums where various unique and often disconnected exhibits of man's endeavors and discoveries are paraded. If any questions are answered it is usually in the manner of a tourist guide to ignorant sightseers: dogmatic and not infrequently incomplete information, to say the least. The significance of the project method lies in this. It inducts the pupil into a problem of his own initiative and the progress stimulates him on, the teacher remaining one giving direction only at critical points, and above all maintaining before the pupil, even in the simplest study, the standpoint of a seeker of truths, not a dispenser of a new sort of "divine" information.

Couple with this incompleteness of the typical public school science teaching the additional fact that everywhere the older and more orthodox elements in the community insist that too radical ideas shall not be given the pupils, lest they lose faith in the traditions and mores that the group-elders approve. To many persons this whole interpretation is very questionable. Many believe that the proper synthesis of science with other materials taught in the schools can be made, and that, moreover, even children, certainly those approaching the high school age, can be given some concrete cues to the interrelation of science and conduct.

This fear of introducing the young into the sciences, especially

biological and social sciences, before they get into college has a disastrous effect upon the later training in the college or technical school. Take evolution as a convenient theory of biology, or take the much discussed matter of American history teaching. In the former the theologically conservative groups frequently dominate in direct and indirect ways the teaching of science in the public schools. The writer knows of many cases where school boards specifically inquire of the candidates for science positions in high schools whether they teach evolution and whether they are members of a Christian congregation. He has in mind one community where an instructor in biology in the town high school put to rout a vigorous ministerial attack on his teaching through an appeal for support to the more liberal and modern churchmen of the state by a series of letters explaining his fight for freedom in his school. Too often, likewise, the teachers of American history are under pressure to conform to the politico-economic conservatism of a given community.

We have, then, from the side of preparatory training, often a mass of excellent factual material, but no integration. The boy or girl knows the rudiments of biology, chemistry, physics, economics and history, but he does not know the first steps of what they mean in cultural progress, in relation to the entire body of science and especially their meaning in relation to social conduct.

In both high schools and colleges we usually find an attitude expressed as follows, if any thought has been given to the matter whatsoever, "Give the student the facts. That is all. They will do the rest," implying that the students have the capacity and inclination to integrate their materials on higher planes. This notion is undoubtedly fallacious. The ability to integrate separate facts and modes of behavior is extremely difficult to induce, as every teacher knows. The inclination to relate the various branches of science to each other is very little encouraged or even thought of. Certain general science courses are a feeble effort towards an alteration in the traditional methods. It is often too late to try to bring about such a desirable viewpoint in a graduate student, when all his previous education has been so dissociated.

As William Graham Sumner said, "Primitive man did not philosophize. That is our way, not his," so, too, the entire matter of integration is one of habit and training, quite as much as technique-learning. No doubt there are many men who are essentially workers with details; they spend their efforts on the minutia of science and "never see the forest for the trees." Perhaps these men can not reach high levels of integration. These men have been described by a man of reputation in science as "highly skilled workmen with

a refined trade." One wonders, nevertheless, what other attitudes these men might take had their early training been otherwise. Is not the matter partly a question of the primary direction of attention?

When the freshman arrives at college his scientific knowledge is crude and disorganized, and his general patterns of mind are those laid down by the mores of the community. His science remains essentially a thing apart. Religious, economic and other superstitions are in control.

Specialization in modern science continues this lack of perspective in college. The average student plunges *in media res* into some special branch, in terms of real or imagined aptitude and interest. He follows the hints and regulations of a major department. Often the rules of the game necessitate a very fixed procedure. True, the line between the branches of the natural sciences is not severely sharp in the first two years of work. Modern biology, chemistry, physics and mathematics tie up closely together in background. The social sciences, on the other hand, remain quite a distinct group, and there is very little attempt to dovetail these together or to relate them in any way to the natural sciences.[3]

The specialized laboratory is the greatest advance which the pedagogy of science has brought us, yet it is not enough. A step forward may be initiated through attempts, in the early college years, at symposium courses in the sciences.[4] But for men who are going into science for their careers there is great need in the senior college and graduate years of training in the methodology of the sciences and the relation of science to living and conduct. In the scattered institutions where such courses are offered the students who should have them most do not register for them. This was the case with the example cited above. The brilliant candidate for the Ph.D. in science worked out his thesis in a laboratory not two hundred yards from the building in which an extremely able philosopher, with good training in natural science also, offered courses in the logic and methodology of the sciences.

[3] Under the leadership of President R. F. Scholtz, Reed College, Portland, Oregon, is trying a very progressive program of building the entire college curriculum around the idea of uniting the sciences and the humanities. The courses in literature, anthropology, psychology and social sciences are through the nexus of cultural history brought into relation to mathematics, physics, chemistry, biology and other natural sciences. This unique effort may prove a valuable educational experiment.

[4] At certain institutions, as at Stanford University, symposium courses in the sciences have been arranged for freshmen and sophomores. These have been worth-while, but there still remains little recognition of the fact that we require also some conscious linking up of the meaning of science, *in toto*, with the cultural values and conduct of the world.

The general training in English universities has many advantages. It is not only a matter of the courses themselves, but a feature of the cultural atmosphere. While the situation in British institutions is not perfectly adjusted, it is a distinct improvement over our own, where the influence of German specialization, abetted by the American business folkways, emphasizing energy and application, makes against the air of discussion and the perspective needed to foster the true synthesis of specialty with cultural values.

It is not to be understood that the student should give himself over to system-making, to philosophizing upon the relations of the fields of knowledge and thus destroy his inclination and energy for careful work on technical problems. What is desirable and perfectly feasible is a minor revamping of the training to include the things just mentioned: general methodology, interrelations, certainly the limitations of the specialities and lastly their nexus with human life. It has been the good fortune of the writer to be associated with students and professional men of different sciences and with men of literary and artistic activities. In probing their ideas and attitudes for synthesis and integration, he has discovered that in those few where it is found, it has come about in chance ways, by contact with a particularly able scholar (as well as specialist), through reading, occasionally by contact with fellow-students. Very seldom is the viewpoint the outcome of a common thread of significance running right through all: science, art and life.

The net result of the present system of specialization, therefore, is the lack in general viewpoint concerning the meaning of science in the large and its relation to the humanities and to life outside the laboratory. Even though the average hard-headed scientists are apt to be "anti-metaphysical," as they proudly put it, too frequently this notion leads them into the most naïve types of metaphysics of their own without their being aware of it. While the writer would not push the need for training in general philosophy, he would suggest that the historical connection of science and philosophy ought to be considered and an effort made to once more relate them. At any rate the basic foundation which we are advocating here is necessary. An awareness of the methodology and limitations of science in general would correct many of the sharp angles of difference between related sciences, for instance, between physics and chemistry on the ultimate nature of matter, or between psychology and physiology over their scope and interpretations. An example of the present status of attitude in regard to this matter is in point.

At an active state university a year or so ago, two or three of the younger faculty-men in the natural science group became mu-

tually interested in the problems of the logic of science, the overlappings and limitations of the various fields. This interest grew, in part, out of a discovery that their own training was lacking in just this matter. Believing that their colleagues in related disciplines would be interested in similar questions, they proposed to the Science Club (an organization of faculty men and women in the natural sciences) a series of meetings dealing with papers and discussions of the fundamentals of science. One not acquainted with the usual attitude in the academic world can scarcely believe that out of a group of nearly forty men and women, practically all of them having the doctorate, only a very small minority showed any interest whatsoever. The president of the club, reasonably well known in his own specialty, was even strongly opposed and in no mild sarcasm remarked that the important matter for every one was to apply himself to his own problem. It was no concern of his what connections or contradictions might occur in reference to related fields. The need of investigation the advocates granted. They were proving their faith by their own research. What they could not grant was the notion that there was no necessity whatsoever of discussing conflicts, contradictions, of taking stock of scientific meaning in-the-large and its place in the cultural ongoing. It is said that the major students of the president of the club illustrate unfortunately the common lack of perspective and consequent confusion in the interpretation of their research.

When one recognizes such an attitude in men of science, what may one hope for in the way of integration in the high school instructor, applied technician and the common man? Again, the example may be unusual, but it throws into relief a common seriousness. The same sort of question was implicit in a recent discussion of a group of psychologists over the type of training for candidates for the doctor's degree: extreme specialization versus broad, general culture, including some technique, of course, or a combination of the two which would produce a human being as well as a machine for turning out research.

The requisite is a balance between the two tendencies. The tremendous growth of the sciences has swept us off our feet. There is some danger in over-specialization, not so much for the general results on paper, as upon the personality of the man. There is more likelihood of dogmatism in science from high specialization, both as regards the assumed importance of one's own field, and from the equal absurdity of "particularistic" theories to account for very complex phenomena. One needs but mention current Freudian psychology with its one instinct, behaviorism with stimulus-response, in anthropology, Lippert's famous theory of the inevitable

correlation of domesticated milk-giving animals with high culture, the large number of single-track theories in sociology and so on. To counteract this extreme there are at hand cultural history, history of science, philosophy and the humanities, giving all together the only proper center around which one's personality and hence one's speciality may turn.[5] The very size of modern science is discouraging, but the fact ought to stimulate rather than inhibit us in the attempt to gain systematic orientation for our students and for ourselves.

Turning from the educational aspects of the topic to those bearing on the public mind, we see another set of forces arrayed against synthesis. In the relation of the scientist and the community the powerful factor of prestige comes into play. Men recognized in their own fields are under the constant temptation to offer their advice on the world in general. This arises primarily from the psychological effects of felt-recognition. The seeds grow rapidly in every one to speak as one having authority. Secondly, the populace, encouraged by the press, looks upon the man of science as a present-day miracle and magic worker. A headline reporting the lecture of a psychologist on abnormal psychology is likely to phrase it in terms of the occult and the mysterious. Sumner pointed out how quickly the masses retouch the scientific notions to suit their own mental set.[6] In view of this the newspapers and their clientele are apt to turn to the men of science in a given community for opinions, not only in their own fields, which are often too remote or abstruse for the ordinary person to grasp, but frequently on matters of the day. Some men of reputation unfortunately take the slight place of newspaper notice too gravely. It means recognition in one's own neighborhood, a thing few scientists have or should much concern themselves with. The social pressure is effective. As a consequence we find Professor X or Y, a specialist, in a remote branch of natural science, quoted in the papers for opinions on law Bolshevism, and Margaret Sanger.

Examples could be multiplied. In the social sciences the danger is peculiarly present, since every citizen, in this country at least, considers it almost a duty, if not a right, to speak on every conceivable subject which touches the body politic. Hence a natural scientist or engineer may regale a business men's club with a discussion on economics, on the errors of proportional representation or a defense of the Open-Shop. Some wonder when a professional politician makes an unscientific analysis of an international banking

[5] *Cf.* H. E. Barnes, "The historian and the history of science," THE SCIENTIFIC MONTHLY, 1920, XI, 112ff.

[6] William G. Sumner, "The Folkways," 1901, p. 47.

situation, but they should marvel more when a natural scientist, say, speaks with arrogant authority on social questions.

Most scientists, it must be said, are suspicious by sad experience of newspapers and desist from comments therein. More frequently men who are technologists and inventors of mechanical devices take to general press publicity and subsequent prestige. To the ordinary person men like Edison are far more important than Michelson and Einstein. The inventor is naturally nearer the folkways; he deals with more or less understandable stuff.

In short, there is a common tendency to universalize authority, both among the followers and in the assumption of authority by experts, executives, religious, political and military leaders. The mass of mankind desires an element of omniscience in its authorities. The populace demands an "all or none" principle. It protects them from doing any thinking for themselves; all that is needed is reference to authority to settle doubtful questions. This dogmatism the scientist ought to resist. Even though the application of scientific principles means predictability and control, it can not mean absolute finality. The progress of science is a continuing process. There can hardly be a staticism, though there may be a reduction of our present acceleration. Only the ultimate limits of man's mind can stop him from stepping forward in the conquest of the universe. Scepticism, as Veblen well says, is the essence of the scientific mind. We recall Abelard's famous dictum: "The beginning of wisdom is found in doubting; by doubting we come to the question, and by seeking we may come upon the truth." The attitude to change one's attitude is invaluable.

Another serious handicap to the scientists themselves is for a man renowned in his own field to throw the weight of his authority towards some pseudo-science. This is illustrated by the interests of men of prestige like Alfred R. Wallace in spiritualism. More recently the movement termed "psychic research" is in point. Men like William Crooks, the chemist, J. H. Hyslop, the psychologist, and Sir Oliver Lodge are heralded as "authorities in science" for this popular vogue.

While the purpose here is not to make dogmatic implications about immortality, one way or another, the fact still remains that, measured by our present criteria in chemistry, physics, biology and psychology, the evidence for the alleged findings of psychic research causes us to hold in abeyance any authoritative pronouncements for the same. The facts of the psychology of testimony, the questionable experimental controls, the whole tremendous effect of "mental set" in producing illusion,[7] the extreme amount of fraud,

[7] The historic case of the N-ray in physics is an example of what a "wish" to see will do to a group of men working in a narrow field. *Cf.* O. Sackur, "N-Strahlen: Ein Beitrag zur Psychologie des wissenschaftlichen Beobachtens," Beitrage z. Psych. d. Aussage: 2; no. 2: 147–154.

conscious and non-conscious, which has been uncovered in asserted demonstrations, especially the relation of "results" to the abnormality of the individuals performing, and so on *ad infinitum*, make the legitimate scientist dubious of the entire matter.[8] The likelihood of destroying the faith of millions of people in the persistence of life after death is infinitely remote if pragmatically desirable. So long as these beliefs do not handicap the highest sort of living, here and now, we may imagine them harmless. It is when they obstruct the enhancement of human life and values through the applications of natural and social sciences that we must consider them a difficulty. It is because they, more or less, tend to block and obscure scientific application, particularly by giving the masses a wrong impression of science, that the lent prestige of a scientist to spiritualism and its ilk is serious.

In some sections of our country health work in the public schools has been in great jeopardy during the last ten years through the activity of certain sects opposing it on the ground of religious belief. In this particular instance men and women of wealth and position in the economic world are prominent protagonists against health inspection and remedial measures. These people bear much prestige in their communities. Let a man of science, even if remote from medicine—in fact, some remoteness of interest actually enhances his importance in their eyes—but speak against this hard-won movement in our schools and he is haled as proof, scientific and absolute, of the standpoint which the religious doctrinaires so firmly hold. The same thing may be said of the fight over vivisection. Some men of standing in certain communities, whose judgment should have led them to more sensible views, have given support to the sentimental and idle men and women who go up and down the country bewailing the "terrible" treatment of dumb animals in our experimental laboratories.

The scientific attitude is rare. The history of man has paralleled, in a sense, the growth of objective attitude. It demands a high development of intellectual powers. For it to touch the entire person, it requires also a high synthesis of the specialized knowledge with the rest of the personality, especially in relation to emotional attitudes on questions where other scientists may be experts, for instance, in reference to social beliefs held dear in the community. The scientist whose whole personality is so integrated is rarer than he with objective attitude in a given specialty and in this way the former comes nearer the great artist, writer and philosopher. Part of the difficulty is due, as we have seen, to the education which

[8] *Cf.* J. E. Coover, "Experiments in Psychic Research," Stanford Press, 1917.

the usual scientist receives, part of it, no doubt, is related to temperament. Some men really seem incapable of escaping a mild type of dissociated living and thinking.

We have spoken of those cases where men of science drift into easy authority in remote fields. Nearer home to most of us is the fact that the intense specialization to-day has robbed men in closely connected fields of the contacts and relations previously held essential. The psychologists know fairly well their physiology and neurology, but little of sociology, which is important when dealing with the social behavior of the individual. The sociologists, on the other hand, know their psychology and biology but meagrely. The economists, political scientists and historians, with brilliant exceptions, know as yet practically nothing of physiology, psychology and sociology. The field called "Education" illustrates particularly the need of training in a number of related fields. To many persons it is unfortunate to see a trend in certain "schools," "colleges" and departments of education towards an inbreeding of their own curricula, under the notion that they can give their students all the training their specialties require. Education must remain secondary to other sciences, and if it is to maintain a vitality, it must keep close to them in preparing its men and women. What can one do in "education" who does not know his biology and mathematics, his psychology and sociology, at least?

Among natural scientists the principal handicap is the divorcing of their technical interests from the ordinary course of living. They lack perspective in reference to the social sciences and in toleration of experts whose knowledge leads into the field of human behavior.

One does not deny the immense pressure which specialization has put upon us all. Once homogenous fields, like chemistry or biology, are now too large for one man to cover adequately. We have indicated above some means of overcoming the problem in the training-stages of scholarship. The fundamental need is a new set of attitudes in the scientists making for well-rounded orientation. Their science in one sense must become an art, it must grow out of an intense personal adherence to the truth, coupled wth toleration and caution regarding types of reality where they are not themselves experts. Before concluding with an implication for social progress, there are a number of features of our present habits of scientists that need emphasis:

(1) There is a certain amount of false stimulus among scientists, in this country particularly, to publish, to get into print. There is almost a research psychosis with some men, which, like all psychoses, dodges the reality of more serious, long-time effort in the attempt to make something immediately publishable. This situ-

ation arises from our academic institutions in large measure. Advancement in position, with resultant betterment of economic status, is closely bound up with the number of papers and books one has to his credit. Then publication, no matter what sort, seems to enhance prestige with colleagues and students. This mistaken emphasis is very likely to encourage shoddy work, and journals in which one may put forth his work may be quite as much a sort of mild curse as a blessing.

(2) We need stimulation to read science in general and the inter-relations which are emphasized in such periodicals as *Isis, Science Progress, Scientia, Science* and THE SCIENTIFIC MONTHLY. There is need just now for a *rapprochement* of the natural and the social sciences.[9]

(3) One fears that the "Ph.D. Octopus," which William James so succinctly described, is in a way to strangle us. The large quantity of mediocre results which comes from men and women rushing through the graduate schools in mad striving to secure the coveted title is disintegrating. Importance is put on having the degree in order to get a position in the colleges or universities throughout the country, not as a badge of patient and outstanding accomplishment. This tendency produces a "set" for quick work which a different emphasis would correct. Many of these people possess ability far above that illustrated in the work they do, but the habits inculcated often prove disastrous. The attitudes formed in the three or four years of graduate work tend to outlast a much longer period thereafter.

(4) Our democratic ideals have had a curious way of producing uniformity rather than diversity in research interests. In France, we have been told there is far greater encouragement of individual initiative in research on the part of the student.[10] In this country there is a very grave tendency in the opposite direction. Reward is put upon conformity, that is, agreement in problem and results with the interests of the man with whom one works. Investigation to examine the fundamental assumptions of one's major professor is discouraged or actually suppressed. The result is a kind of rigid discipleship, almost an intellectual sycophantism, which is difficult to overcome. On an occasion of a dinner tendered Professor Jowett by his former students, he remarked that the greatest compliment ever paid him was that of a considerable number of able scholars whom he had trained not one of them agreed with him. One wonders sometimes if the spirit of conformity in research is not a

[9] *Cf.* Robinson, *op. cit.*; also, W. M. Davis, "The reasonableness of science," THE SCIENTIFIC MONTHLY, 1922, XV, 193ff.

[10] P. Boutroux, "Science in France," THE SCIENTIFIC MONTHLY, 1921, XIII, 435ff.

phase of the wider standardization and mechanization of life in the modern age.

(5) Most of the men who receive advanced training in the sciences are not properly classified as scientists at all. Their work, however, brings them close to the interests of research. These are the applied technologists, ranging all the way from the usual medical practitioner to the electrical or chemical engineer. All these should maintain some interest in the perspective of their work in the social-economic world in which they live.[11] The ignorance of allied fields is illustrated by the movement of the industrial engineers, who, ignoring deep-seated instinctive trends and attitudes in workmen, went ahead with stop watch and efficiency schemes to increase the productivity of industry. A knowledge of psychology and sociology might have saved them many disappointments and made possible more adequate and humane methods of accomplishing what they set out for. Even the applied psychologist in industry to-day is rather ignorant of the socio-psychological factors behind trade-unionism, such as fear of economic insecurity and the like.

To recapitulate the implication of all this: While we need the humanizing of knowledge of which James Harvey Robinson has so brilliantly spoken, it is particularly through the integration of attitudes and action among scientists and their near-kin, the technologists, that we may look for acceleration of social change. Likely enough some retrogression may result from a lack of perspective. A narrow conception of, a mere technical interest in, chemistry, for example, may conceivably result in a horrible use of chemicals in the destruction of the very civilization chemistry has had such a place in producing. Not only must the scientists realize the interrelations among their fields, but even more so must they see that unless an integration of natural and social science with ethics and living be made, no lasting progress will be possible.

When the scientists themselves begin to see the significance of these matters, they will be able to forge for the technicians, and through them for the masses, tools with which to pry the universe further to our own liking. One may have a pious hope for a future general dissemination of the scientific attitude in the masses, but the history of man's culture has given us little basis for belief that this wish may be materialized. There is actually more evidence that the general run of mankind always has been and always will continue to be controlled by socially concrete and technological frames of behavior laid down for them and carried on by prestige-bearing persons in the group. Therefore, the integration of the

[11] *Cf.* T. Veblen, "The Engineers and the Price System," 1922, for comment on this matter.

scientific attitudes among the scientists and technicians themselves is highly desirable, in fact inevitable, if the results of science are to replace, except helter-skelter, the schemas of the traditional medicine-man and magic worker. For the men in natural and social sciences must become "the authorities" who set the patterns of man's behavior. When the cooperation of scientist, technician and socio-economic executive is formed, we may hope to see the day of rational ethics and really humane living approaching. The present failure of science to be applied humanely for social welfare rather than for special privilege and economic power may in time prove a great barrier against its ultimate importance for the common run of all. Science is but a fraction of human culture and until it is so recognized it must remain essentially apart from serving as an integrative principle in the mutual development of personality and a sane social order. For the scientist, no matter how abstract and removed he is from the present life to-day, must not forget that ultimately science must pay its debt to the society which makes it all possible.

EDWARD LIVINGSTON YOUMANS, A NATIONAL TEACHER OF SCIENCE (1821-1887)[1]

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In Europe some of the greatest investigators have carried on their work independently of the universities and other teaching institutions. Many names occur at once: Leibnitz, Descartes, Pasteur, Darwin, Galton. In the United States it seems that the greater scientists have usually been teachers. Agassiz, Asa Gray, Rowland, Newcomb, J. D. Dana, William James, all held teaching appointments. If this difference be a fact, the explanation of it may be difficult to discover. It can not lie in the leisure of the American university teacher, for as compared with the European conditions, such leisure does not exist. Our teachers have done scientific work of greater or lesser moment, if not in spite of their teaching, then certainly in addition to its heavy load.

As we have had investigators who were primarily and regularly teachers, so we have also had some great teachers who have maintained no connection with a school, or better perhaps, teachers whose school was the nation as a whole. In this class Emerson would be found. It is to this class that Youmans properly belongs. Although he was called Professor Youmans his only collegiate connection was a very temporary and rather irregular one with Antioch. And just as he was not a professor, so he was not a discoverer. As a scientific investigator he has to take a low rank; but as a teacher of the science discovered by others he achieved a high one. He taught a nation by his books, by lectures and by means of a well-known journal which he established and for many years directed, *The Popular Science Monthly*.

Edward Livingston Youmans was born near Albany, New York, in 1821. He was, therefore, about two years younger than James Russell Lowell and two years older than Matthew Arnold; and, although he visited old England and New England frequently and was in close touch with authors and publishing interests in the two continents, yet one can recall no reference to either Lowell or Arnold in his correspondence nor any indication that he ever saw either of them. Although he was a good writer and an excellent

[1] The biographical facts of this article are for the most part taken from the life of Youmans by John Fiske.

speaker, he was almost blind on the literary and artistic side. Science sufficed him for a life-interest, science and human nature, for he was the friendliest of men.

He came of English and Dutch stock, as beseems a man from central New York. His mother had been in early life a school teacher; his father was a farmer, wheelwright and wagon-maker. They were not wealthy, nor were they poorer than the average of their community in rural New York one hundred years ago. But money was scarce and wages were often paid in kind. It was in the days of homespun, hand-work, hard work and long hours.

Edward—his given name was Livingston after a revered pastor and the Edward was self-adopted later on—was an industrious and capable lad and made good use of the meager cultural opportunities of his environment. Because of his ability his pious grandmother, and his mother, too, wished him to become a minister. And as he travelled the unexpected line of development which he did follow through life he sometimes—and entirely seriously, of course—assured his rather Puritan parents that it was not necessary to be a clergyman to assist in the work of saving souls. In his mind the sharp distinction between sacred and secular affairs had faded and he regarded the spread of scientific teaching and the imparting of practical information as the most valuable and important work in the world.

It is apparently not difficult to see the reasons for this conviction or the steps by which it was attained. Labor-saving devices in the house, improved implements, better and more abundant fertilizers for the thin acres were immediate necessities. The boy's early life was spent in farm and mechanical labor. Educational opportunities were limited partly because of the environment and partly from lack of financial means. Although he read whatever he could get, the supply was limited; and yet it included "Don Quixote," some of the ancient classics in translation and, particularly, Comstock's "Natural Philosophy," a chemistry by the same author and Buffon's "Natural History." It may be that his mind had an inherited bent toward scientific thought and study. Certainly, the most impressive achievement of his boyhood was the construction of a centrifugal water-wheel which excited the interest of the neighborhood, because it actually revolved and especially as it moved—as such wheels do—in a direction opposite to that of the stream which propelled it.

Since he would not be a minister and since he would be an educated man, his parents wished him to become a lawyer. He seems to have favorably considered this goal; but before he was to enter upon the special studies of a profession he suffered from an affec-

tion of the eyes which with its alternate improvements and relapses lasted from his seventeenth to his thirtieth year. His trouble was so serious that it would have reduced a less indomitable personality from an aggressive worker to a charge upon his family. In a period of improvement he had begun teaching in a country school in order that he might help to defray the expense of a prospective college education. Renewed illness cut short his teaching career. His difficulties were aggravated by overstrain, probably on the theory that blindness is to be preferred to ignorance; by exposure and colds, which led to severe inflammation; and finally by the ignorant malpractice of a quack oculist, which completely extinguished the sight of one eye and permanently impaired that of the other.

In the hope of securing competent medical advice he went to New York City when he was about twenty years old. He did get aid and he found work and sympathetic friends, among them Horace Greeley and Walt Whitman. At times his vision improved so much that he was able to find his way unaided about the city; but the least exposure or nervous excitement would cause a relapse into total blindness that often lasted for weeks. By the age of thirty, as a portrait taken at that time shows, he had developed the characteristic facial expression of the blind, and his friends and sometimes he himself had given up hope that he would ever recover his sight to any useful degree; yet recover he did and that almost suddenly, as will presently be told.

Meanwhile he did not sit idly by. He found odd jobs around newspaper offices, writing advertisements and reviewing or making summaries of new scientific books. Much of the work could not be done unaided. Friends read to him when they could spare the time and also took his dictation. However, like Prescott, he invented a frame to hold his paper and guide his hand. Eventually his sister Eliza, who had scientific tastes like himself, came to him, and the two formed a lifelong partnership in work reminding one of Sir John Herschel and his sister Caroline. Eliza found a position as a teacher. On Saturdays she had access to a laboratory and carried on experiments in chemistry and studies in botany. Evenings she read to Edward, recounted the results of her studies and prepared his manuscript.

He was not lacking in projects. One was the preparation of a history of scientific discovery. With his sister he ransacked the libraries and the bookstores of the city for information. On one trip the two went into Appleton's, when Mr. W. H. Appleton, then head of the firm, seeing the situation, instead of selling them the book for which they asked, offered to lend it to them and also any

other book which they might want. In this way began a connection fortunate and profitable both for Youmans and for the firm in question. When the history of scientific progress was well under way, Youmans found himself anticipated. Another book on the same lines was published in New York. A second project was the preparation of an arithmetic more practical than those then in use. He planned to introduce concrete problems taken from practical affairs and from current science and to use in the problems the constants of the various sciences instead of the abstract and unreal problems and quantities with which school arithmetics were then filled. At once he began writing the book. Again he was anticipated, this time by Horace Mann, who, as co-author with Pliney E. Chase, in 1850 published a book called "Arithmetic Practically Applied." Of this book, which is never mentioned by the historians of education who make so much of Mann, a competent critic, Mr. J. M. Greenwood, says: "A revised edition ought to be in the hands of every teacher. It has never been properly appreciated, and few copies are in existence; even the publishers do not have a copy."[2] But before Youmans learned that his ideas on arithmetic had been anticipated he had succeeded in another direction.

At this time, that is, about 1850, and for years after in many cases, chemistry was taught in schools from a text-book only, without laboratory or demonstration. Even Harvard followed this plan until the fall of 1851, when chemical demonstrations by the instructors were introduced. Laboratory work by the students came still later. It occurred to Youmans that if by means of a chart and colored inks chemical combinations could be visually represented to students, clearer ideas would result. Doubtless his blindness was here an advantage in disguise, for in the long intervals of sightlessness he could not follow his sister's experimentation except as he visualized her descriptions of the processes. The student without a laboratory appeared to him very like a blind man. Accordingly, he devised diagrams and combined them into a complete chart showing the theory of chemical action as then understood. The chart was exhibited and called out much interest and favorable comment at a fair held in Castle Garden. It was then put on the market and had a wide sale. But its chief importance to Youmans was an indirect one, for it led him to the successful completion of his first book, "A Class-Book of Chemistry," published by Appleton's. The preparation of the text had been most carefully and, therefore, laboriously carried out. He speaks somewhere, although

[2] Report of the U. S. Commissioner of Education, 1897–98, vol. 1, p. 854; and also W. S. Monroe's "Development of Arithmetic as a School Subject," p. 118. Messrs. E. H. Butler & Co., Phila., were the publishers.

perhaps not in connection with this first book, of breaking up and rewriting a certain passage fourteen times. When he had several chapters ready he sent them to Appleton's for an opinion. The reply soon came as follows:

> These pages give promise of an excellent work on chemistry. The author evidently understands the science and possesses a clear, logical mind. His manner of presenting the various subjects is quite full, and his thoughts are practical and such as can not fail to make a striking impression on the youthful mind. The "atomic theory" and the subject of chemical combination are not more clearly handled in the works of either Silliman, father or son. More attention should be paid to punctuation.

With golden words of praise like these, including the comparison with the elder Silliman, the Nestor of American science, any young author might well have been content, and the stricture upon his punctuation must have seemed a slight matter. The book was finished and published in 1851. It was twice revised by the author and sold in his lifetime 100,000 copies or more. This was by a long way his most popular book.

Fortune smiled, the future looked bright, and indeed it was so. Success relieved his mind of its care, his general health improved and with this improvement his sight in one eye returned so that he could read easily and could, of course, go about and was able to recognize his friends. His face no longer gave the impression of blindness. "When the chemistry was finished in the autumn of 1851, its author had been for eleven years under the care of an oculist." Now and for the rest of his life he could dispense with such service, but he was always very nearsighted. It was perhaps for that reason that he cared nothing for scenery—he did not enjoy the Highlands of Scotland nor the Alps, and thought art criticism a humbug.

The second phase of Youmans's life now opened, his career as a lecturer on science. He was thirty years of age. His speech was fluent; and of its raciness we will soon see some examples. He had read and listened to a great deal of scientific literature, had thought much in his hours of darkness upon the deepest as well as the most immediate scientific problems, had heard great scientific lecturers, including Agassiz, and had been prepared for all this in boyhood and youth by a course of observation and investigation in a laboratory not to be utterly despised—the old-fashioned farm. Going as far west as Wisconsin—and Wisconsin was the Far West then—and covering chiefly the Old Northwest, New York and Pennsylvania, he pursued his new vocation for seventeen years (1851-1868). This was the period when the lyceum platform was still popular, and when the renaissance of science under the influence of the theory of evolution had all the interest of a great discovery

for the young collegians and high school students in regions which public education was rapidly preparing for the reception of the new ideas.

In the middle of this period of lecturing when he was making a place for himself both among the American people and in the publishing house with which his interests became more and more identified, Youmans formed a friendship with Herbert Spencer. He had seen a review of Spencer's "Principles of Psychology" in the year 1856 and had sent to London for the book. Both he and his sister were interested by the author's theory of mental development, read the same writer's "Social Statics" and then began to search the British reviews of the day for his unsigned articles. This was several years before the "Origin of Species"; and it is another bit of evidence that the thought of evolution was a stimulating one in many minds at the middle of the last century, including those of these self-taught scientists of New York.

The first letter (1860) of Youmans to Spencer is so informing and characteristic that we quote:

Dear Sir: My friend, Samuel Johnson, Unitarian clergyman, of Salem, Mass., yesterday called my attention to a letter and circular from yourself, proposing a reissue of your writings. I was not only greatly pleased with the idea, but the circumstance was especially fortunate for me, as it gave me a clue to your whereabouts, which I had for some time sought. I was on the point of writing to Dr. Chapman [editor of the *Westminster Review*, for which Spencer had written] for your address. My purpose was this: I meditate the compilation of a volume designed to present the increasing claims of science upon teachers and the directors of education, to contain the addresses of Faraday, Whewell, Tyndall, Paget and Daubeny before the Royal Institution, on the popular claims of their respective branches of science, together with the address of Agassiz on kindred points, and your own article in the *North British* (I think), which was omitted from the edition of your essays. There is still another article, the opening one in the *Westminster* for last July—"What knowledge is of most worth"—which I wish to include, and my solicitation was to find its authorship. I concluded before I had read a page of it that you wrote it; the full perusal strengthened my conviction; yet, of course, as I may be mistaken, I wish to find out about it. I might have applied to the editor of the *Westminster*, but Scott, the republisher, tells me the conductors are often shy and delicate about giving this kind of information. I should therefore be glad of an assurance from yourself; and if I happen to have been mistaken, would you not probably be able without trouble to inform me who the author is?

Respecting the plan of your publication, I had no opportunity to learn anything, as I had not time to read the circular. But whatever you propose in the matter I fully accept, and will most gladly do anything in my power to forward the enterprise. I have published several elementary books by which I have been somewhat mixed up with book men and the book business, and this circumstance may afford me some opportunity to aid the object. I am more or less connected with the lyceum system throughout the country, and, dealing with scientific topics, I fall in with the class of men who would take most interest in your current thought. . . .

The prospective book to which this letter refers did not become an actual one until 1867, when he edited and the Appletons published "The Culture demanded by Modern Life," a collection of addresses and arguments by various authors on the claims of scientific education. Spencer's reply indicated his wish to retain control over his essays on education, as follows:

> . . . Referring to your question concerning the article, "What knowledge is of most worth?" you are right in ascribing it to me. I should, however, regret to see it and the one from the *North British* included in the volume you contemplate, because I am myself hoping, in the course of a year, to republish these articles, along with an equal bulk of matter on the same topic, in the shape of a volume on education.

Spencer's "Education" was shortly thereafter offered to Ticknor and Fields, Boston. As they refused it, Youmans persuaded the Appletons to take it, and also to undertake the publication of Spencer's other works.

More and more he became not only the "interpreter of science for the people" and the "apostle of evolution," as John Fiske has happily named him, but, in particular, the leader of the vanguard of the Spencerian philosophy in America. Indeed, he became far too much a mere disciple. In advertising Spencer's ideas and writings and looking after his business interests he spent as much thought on that author's affairs as some successful men spend on their own. One illustration of the length to which he would go is found in a note from Spencer, from which I copy:

> I see in the account [from Appletons, his American publisher] the item, "seven copies of the Essays sold to Professor Youmans." Surely you have not been throwing away your money on my books to give away! If there are any presentation copies which you think it well to give, pray always order the Appletons to send them and debit me with them.

When Spencer, before his writings had become popular and profitable, had sunk five or six thousand dollars in the publication of his philosophy, Youmans persuaded American admirers of the English thinker to make up a purse of seven thousand dollars, and by representing that it was not intended as a reward or a mere gift but as an investment to insure the continuance of important work, he presented the matter and the purse so skilfully and delicately to Spencer that a refusal would have seemed ungracious. In a letter of about this time, Christmas, 1864, Youmans wrote:

> Henry Carey called in to blow up the Appletons for publishing Spencer's British free-trade doctrines. Spencer was an upstart; his system would soon die, like Comte's and Mill's. Said W. H. Appleton, "I can tell you one thing—Spencer won't die as long as Youmans lives."

Youmans was married in 1861 to Mrs. Lee, the widow of a New York lawyer and jurist. The following year they visited England.

One of his first objects was to see Herbert Spencer. They found him in Scotland, and he brought them back to London to meet Huxley and other scientific workers. On this first of half a dozen visits to Europe he also spent some time in studying English education, particularly the Borough Road training school for teachers, and attended the meeting at Cambridge of the British Association for the Advancement of Science.

To arrange for the overseas publication of his book "The Culture demanded by Modern Life," already mentioned, he went to England a third time in 1868. The volume contains papers by Tyndall, Huxley, Liebig and others, essays which he exhumed from the transactions of learned societies and the files of periodicals and to which he thus gave a new and wider currency. There are also two papers by Youmans himself: "On mental discipline in education" and "On the scientific study of human nature." The second of these articles was prepared in England and was delivered as a lecture before the College of Preceptors. It presented the view that human nature is a subject for scientific study and stressed the importance of physiology in that study. Its point of view would still be considered a modern but no longer an advanced one. In a letter to his sister Youmans gives an interesting account of the delivery of this address, from which one may quote a few sentences:

> The lecture on the "Scientific study of human nature" came off as per appointment at the room in Queen's Square, where you heard Hodgson. . . . Kitty [his wife] went with me. Just before I began, in came Tyndall. I thought I saw through that dodge in a moment. Spencer is out of town . . . and as he was evidently solicitous about the result he got Tyndall to go. Whichever way it be, it was fortunate, and I am certainly much obliged to him for his consideration, for the meat was too strong for the babes. They were restless, and as I said thing after thing, a dozen pens sprang convulsively to paper, to note them down and blow them up. There was the closest attention, and at all events I had them well in hand. At the close there was cordial applause—as usual, I suppose. A gentleman then arose, and said he was attracted to the meeting by the announcement of my name, having read a very remarkable argument in the shape of an introduction to a work on chemistry lent him by his friend, Dr. Farr (to whom I had given a copy), and he said, "I was, therefore, less taken by surprise at the paper we have just heard than most of you have evidently been." After a very pleasant and excellent address, in which he said Locke had laid down the true view of the basis of education two centuries since, which, if followed out, would have produced the most beneficent results, he sat down and Tyndall arose. He made an exceedingly neat and happy address into the very notch of the case. He put the plaster on large and thick and close, as he best of all men knows how to do and the consequence was that all subsequent remarks were but adding lesser patches. . . . Tyndall escaped before I could speak to him, but I dropped a note to him next morning, thanking him for his kind consideration in coming, for his too partial remarks, and for his shielding me from the little hailstorm which I should have undoubtedly experienced otherwise. He replied, saying: "I quite expected the little

hailstorm and was astonished to find what you said (for the view was very strong for such a place) so heartily appreciated. Believe me, when I say from my very heart, the paper surprised me as much as it delighted me."

It turned out that Spencer had not sent Tyndall, but that, as was amusingly common with the philosopher, he did not arrive because he was under a wrong impression in regard to the time.

The "Culture," in which this address was inserted, had a wide sale and has not by any means been forgotten even now, as one may see, for example, by looking into the third volume of Graves's "A History of Education."

The two most important achievements of his life were, doubtless, the founding of the "International Scientific Series" and of the *Popular Science Monthly*. The "Series" came first, and Youmans on his fiftieth birthday found himself on the mid-Atlantic on his way to engage English, French and German contributors to the venture. Among the foreign scientists whom he introduced to American readers through this series of books were Bain, Buckle, Lecky, Tyndall, Helmholtz and Darwin. During its editor's and projector's lifetime more than fifty volumes were issued and the series had proved a decided success. The arrangement was for the simultaneous publication in America and in foreign countries of authoritative scientific books for the people. Youmans, a man of the people, by his service on the popular lecture platform speaking on scientific subjects, was well qualified to estimate the interests and the understanding of the public. And, on the other hand, the confidence of Spencer, Huxley, Tyndall, Lubbock and, from this time on, of Darwin also, in his acumen and his business honor, went far to smooth the way with the scientists whose cooperation was essential. Youmans went on the theory that popular scientific books should be written by the masters. The "Series" was opened by Tyndall's "Forms of Water" and one of the most successful volumes was Spencer's "The Study of Sociology." An incidental although not unforeseen result of the publication arrangements was that the authors could enjoy the advantages and pecuniary rewards which were only long after secured to authors in general by international copyright.

Hardly was the "International Scientific Series" well launched when the *Popular Science Monthly*, full-rigged, was also set afloat; or perhaps we should adopt the figure which Youmans used and say that it had a very short period of gestation. If so, the *Popular Science Monthly* was born in May, 1872. Although it has changed its publishers, its editor several times and its name (to THE SCIENTIFIC MONTHLY), it has always been one of our leading scientific periodicals.

The idea of a magazine had been under consideration by You-

mans and the Appletons for several years, and they had indeed made one not very successful venture with a weekly; but when Herbert Spencer in March of 1872 sent Youmans the first instalment of "The study of sociology," the ardent recipient wrote: ". . . I decided upon our course two minutes after getting it. I determined to have a monthly at once, and in time to open with this article. It was vital that these articles be not exposed to the temptation to reprint them in pamphlets." And, although not at all a miracle-man in any sense of the word, when Youmans decided to have anything he generally had it. In this way *The Popular Science Monthly*, a magazine of 128 pages, with an original article by Spencer, a translation from Quatrefages by Eliza Youmans, a liberal use of selections, a few editorial pages and some book reviews, was started.

Clippings from English magazines were for a long time used extensively in the make-up of the *Monthly*. And although the scissors can hardly be regarded as a proper editorial instrument, yet they were frequently used; and very carelessly at times, for Youmans in one case admitted that he had inadvertently printed (Vol. VI) a "medical humbug" article only because he had not read it through.

The character of the *Monthly* was decidedly popular rather than scientific, and scientists complained of this, notably Simon Newcomb, although he remarked that the journal was improving in this respect. We must note that it was in the 70's when Newcomb deplored the scarcity of American scientific research and especially "our beggarly and humiliating showing in the exact sciences." Youmans replied that his work was necessary, for the scientists themselves had rejected popularization and had left it to half-instructed men. He was on safer ground when he added that the *Monthly* was founded to educate the non-scientific public in scientific matters.

The conception of his task also explains the nature of his editorial writings. He dealt with many subjects, current scientific progress and events, the visits of foreign scientists of note, the controversy between science and theology, and, more than any other one topic, scientific education. Criticism of the literary content of education and especially of the stress placed upon the "dead languages" is abundant in his columns. He was hardly fair, although the work which he tried to do needed doing. Perhaps hard blows were required to open any door at all by which science might enter into the more conservative schools. Gentle as he was by nature, when he was writing on this subject he seems to have preferred to borrow the iron sledge-hammer of Spencer rather than the ringing

silver mallet of another friend. It was Tyndall, not Spencer, who had written:

> Is there no mind in England large enough to see the value of both [science and philology], and to secure for each of them fair play? Let us not make this a fight of partisans—let the gleaned wealth of antiquity be showered into the open breast; but while we "unsphere the spirit of Plato" and listen with delight to the lordly music of the past, let us honour by adequate recognition the genius of our own time.[3]

Youmans spent his life, if we may use a quaint old English phrase, in "the diffusion of scientific knowledge." As a survey of his editorials in the *Monthly* and of his other publications has shown, he was interested not only in science but especially in the teaching of science. Great scientists, as well as those less great, are sometimes tempted to look askance at popularization, to view teaching, this dealing in the small change of scientific currency, as piddling business; as if, without showing their competency with small sums, children were to be entrusted with large. Teachers, on the other hand, have their own views of the man of science. They may regard him as narrow and remote, somewhat inarticulate even in his own proper field and socially a feckless person. Rarely would either of these recriminatory views be wholly true, yet the tendencies are perhaps common enough to be recognized.

The scientist may become so engrossed in his specialty that he will do little or nothing toward the spread of his discoveries. Sometimes he fears controversy and its time-consuming entanglements. So did Newton. His views called out such opposition that he "was tempted to publish nothing." "I was so persecuted," he wrote to Leibnitz, "with discussions arising from the publication of my theory of light that I blamed my own imprudence for parting with so substantial a blessing as my quiet to run after a shadow."[4] But while fame may sometimes be merely a shadow the results of publication can be shown to be thoroughly substantial.

The value which accrues to science itself from its wide dissemination is great. The wider the extension of a new doctrine the greater is the stimulation of latent scientific talent. The spread of a new idea attracts new workers into the scientific net. While teaching, whether by voice or pen, through illustration, experiment or argument, does encroach upon the expositor's time—time which might be devoted to further investigation—it is not time lost if it calls out new recruits.

As Youmans no doubt perceived, scientific theories gain greatly from the effort to clarify their thought and to expand it to the point where youth, and perhaps dullness, can understand it. The

[3] Essay by Tyndall in "The Culture demanded by Modern Life."

[4] David Brewster's "Life," p. 63.

meaning of scientific discovery becomes clearer by its exposition; and original ideas may be lost for a long time because they are not presented so clearly and voluminously that they can make an adequate impression upon a large public. The history of science furnishes many examples, Mendel for one. This point was well understood by one of the greatest of scientists and of scientific expositors, Charles Darwin. In the autobiography which is included in the great "Life and Letters" by his son (pp. 69–70), Darwin wrote:

> . . . our joint productions [A. R. Wallace's and his own in the *Journal* of the Linnean Society in 1858] excited very little attention, and the only published notice of them which I can remember was by Professor Haughton of Dublin, whose verdict was that all that was new in them was false, and what was true was old. This shows how necessary it is that any new views should be explained at considerable length in order to arouse public attention.

Darwin's whole account of the preparation of the "Origin of Species" and his other writings, of their publication and their effects is of interest and practical importance to scientific writers.

Teaching and popular presentation, however, require talents of their own and somewhat different from those required for original work. The same man may excel in both directions as did Darwin. Yet, as originators are rare, their time is correspondingly valuable to society. Youmans did good service by stimulating the production of manuscripts, by editing them and by developing a market for new ideas. His keen, trained intelligence and his sustained interest in scientific research and discovery fitted him on the scientific side for this task.

Influence is hard to trace and even more difficult to evaluate; but there is considerable evidence that as a writer on chemistry, as a lecturer on science, as an editor and as the founder of an important journal he was widely influential upon the growth and spread of science in America. "I am not among the fortunate mortals," he wrote in 1883, "who do work that is to survive. Yet *The Popular Science Monthly* is bound up in all the American public libraries, and it will hold its place there by sheer force of its bulk—it will hold over at least into the next century; and I am contented that it contains evidence that I knew a good thing when I saw it." With this modest opinion we can not, except on the score of its modesty, disagree.

SOME "SOCIAL NUISANCES"

By W. W. KEEN, M.D.

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I HAVE read with great satisfaction and keen enjoyment Professor Knight Dunlap's paper in THE SCIENTIFIC MONTHLY for September, 1923. With almost everything he says I am in hearty accord. With two—the Antivivisectionists and Prohibition—I am in disagreement on some points.

I—ANTIVIVISECTION

(A) That experimental research sometimes does inflict pain on animals is true. That some wanton and reckless experimenters disregard such pain is also true. The latter have lost caste in the profession and, in any case, are few in number and becoming constantly fewer. "Inflicting pain" is not synonymous with "cruelty." For instance, to ride a horse to death to procure medical or surgical help in an emergency, or to sacrifice lives and cause even hundreds of men to suffer mutilation in a "feint" attack to mislead the enemy from the real attack is as old as war and is not "cruelty." The 17 hogs which yielded up the secret how to abate hog cholera and almost wholly to conquer it, did suffer pain undoubtedly (though pain diminishes from man downwards in the scale of living beings very rapidly, as judged by our only standard—the exhibition of suffering), but was not this infliction of pain justified a thousandfold by the saving of the lives and suffering of millions of other hogs?

So, too, by infecting 25 monkeys and 100 guinea pigs with the poison of cerebro-spinal meningitis, Flexner was able to reduce the mortality of that dread disease from 75 per cent., and sometimes far more, to 25 per cent., and sometimes far less. Does not common sense justify this vicarious suffering? Should it not be praised and fostered if we can thus discover a trenchant weapon against scarlet fever, measles, cancer, etc., instead of being condemned or still worse prohibited?

When the Germans, in 1915, at Ypres, in spite of their thrice repeated solemn promise at The Hague and in the Treaty *not* to use poison gas, did use it and slew some thousands of brave Canadians, when its internal effects and the means for protecting our soldiers were wholly unknown, what was the proper course to pursue in order to protect our soldiers:

(a) To experiment upon dogs, which undoubtedly suffered great pain, and quickly find the means of protection, or

(b) To await the experiments the Germans inflicted on our soldiers and slowly and imperfectly learn by their sufferings and death how to combat this dreadful new weapon?

I am almost ashamed to ask this question, for common sense and humanity combine to commend the first and quickest.

(B) Would Professor Dunlap be satisfied if, at the Massachusetts Institute of Technology, no engineer was allowed to see an automobile engine in motion but only as a motionless dead machine? I trow not.

As I know by my own personal experience and as a teacher of surgery for over 40 years, to see only a dead, motionless heart gives only a faint idea of its wonderful action. How it thrills me to see it actually in active motion! And then to destroy the little group of cells in the furrow between the auricles and the ventricles, and to see how the regular sequence of the normal contraction and relaxation of the auricles and ventricles changes to unregulated action, to wild, physiological chaos! Never can a mere description or a mere inspection of this wonderful human "motor," as a dead and motionless machine, give a *real* idea of its action and its value.

The removal of the pancreas in a few dogs—which all died from diabetes—was the key to the discovery of insulin. Who would dare to stay the hand of the experimenter who, by such means, led to the discovery of insulin?

Professor Dunlap objects to "mere demonstrations" of the workings of the heart, lungs, intestines, uterus, etc. To my mind they are essential and unavoidable means for giving human "engineers"—the physicians, surgeons and obstetricians, to whom we all commit our own lives and the lives of our dearest—a lively and living idea how these organs perform their functions.

Some of these demonstrations can be carried out by killing the animal and at once removing the heart or inspecting it and other viscera, and if so, it would, of course, to some extent answer the purpose.

II—Prohibition

The able editor of the *Atlantic Monthly* for October (p. 573) commends an article on this subject as an effort to "refocus thought upon what has become a condition and not a theory." Let us look, therefore, upon some of the existing conditions.

In many, if not in most (or all?) of our treaties with the Indians, the sale of liquor is prohibited. That this provision has been shamefully violated is not the question. The *motive* for such a prohibition and its *effect* when and where *made* effective, is the

question. I venture to say that in no place in which this provision was made effective by the Indian agent of the government was the effect anything but beneficent.

In introducing civilization among the African backward nations, the sale of alcoholics and of arms and ammunition has in general been prohibited. Why? Evidently, because as in the case of the Indians, its harmfulness—great harmfulness—was acknowledged. Again, wherever this prohibition has been effective, the result has been to the good.

Are not these two instances convincing as to the prevailing opinion of civilized governments and peoples that the indiscriminate, unrestricted use of alchohol is noxious? Did anybody ever raise the question of the restriction of "personal liberty" in such cases? If any one had done so, would not common sense have brushed it aside as irrelevant and even arrant nonsense?

Is "personal liberty" different in civilized and uncivilized nations?

In the United States the 18th amendment was passed, as declared by the Supreme Court, in the perfectly legal way prescribed for amendments of the Constitution. It was debated in private and public, in the public press *ad nauseam*, in legislatures, in both Houses of Congress, and recommended by both of these Houses, and has been adopted, if I remember rightly, by 46 states out of our 48. It is the "supreme law of the land" as declared by the Constitution itself. It has been affirmed that even before its adoption over one half of the United States was already "dry."

Salus Populi Suprema Lex

The blessings of prohibition were eminently shown when it was solely a war measure, not only in diminishing the evil of drunkenness, but also the almost worse evil of venereal diseases.

Its blessings, to-day, in spite of its defective enforcement, I showed in my address in Paris as President of the International Congress of Surgery in 1920 (*Annals of Surgery*, September, 1920).

It has been a boon to the mothers and children of the land. "Tell us how to vote dry" was the pathetic cry of the working women of Philadelphia to speakers at many public meetings. Their husbands, instead of squandering their money on drink, were spending it in better clothing, rational amusement and loving care of their wives and children. Their savings banks accounts were greatly increased all over the land.

The testimony of large employers of labor (*Manufacturers' Record of Baltimore*) was overwhelmingly in favor of prohibition. Their turn-over of labor was far less; their men were on hand on

Monday morning instead of sleeping off the sprees of Saturday and Sunday. Accidents caused by minds befuddled with drink were far less frequent, saving money to the employers and life and limb to the workers.

Many of our railroads prohibit any drinking by their employes while on duty. Why? For the same reasons as above given. It pays the railroads in actual cash to stop drinking, as it does the employers in manufacturing and commercial establishments.

Professor Léon Bernard, of the medical faculty of the University of Paris, in his report on what he had seen in a widely extended visit to this country testified to the same good effects of prohibition (Bulletin of the Paris Academy of Medicine).

"The effect of alcohol on longevity" is a study based on nearly 6,000,000 persons whose lives were insured in the United States, Canada and Great Britain and showed that in direct proportion to the greater use of alcohol the death rate increased from 100 per cent., for non-users, up to 182 per cent.; the average of all grades of drinkers being 132 per cent.

Said an intelligent Englishman to me lately: "In England we shall be driven to prohibition for economic reasons. A non-drinking nation for the reasons just given will always be able in the long run to undersell a drinking nation in the markets of the world."

That liquor can be, and is, obtained so freely is largely to be laid on the doorsteps of Congress. They refused to place officials under the Civil Service Board and made the appointments—to their shame—political appointments. This effect is well shown by Mr. Haywood in the *Atlantic Monthly* article already quoted—the very men appointed to enforce the 18th amendment in many cases are false to their trust and abet its violation. "What are we going to *do* about it?" he asks. Give the country time, and the violators of the law will find out. The great mass of the people, the working men especially, are in favor of prohibition and Congress and the officers of the law will find out and trim their sails accordingly. Public opinion will compel observance of the "supreme law of the land."

THE BIOTIC FACTOR IN FORESTRY

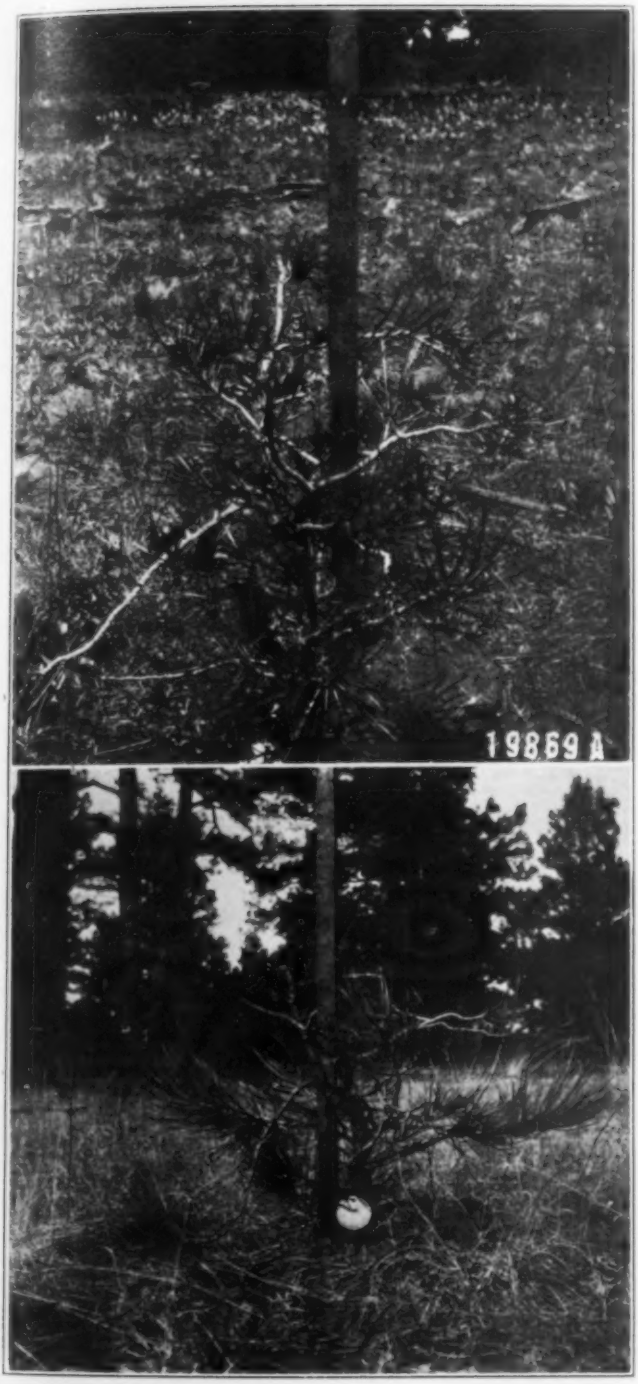
By EDWARD N. MUNNS

FOREST SERVICE, WASHINGTON, D. C.

ALL too often the biotic factor in forestry is overlooked. We take note of the soil and its moisture, of evaporation and of wind, of cover conditions, altitude and methods of logging, and ascribe to one or the other the reasons for the presence or absence of reproduction. All too often we look for the difficult thing, sometimes overlooking because it is too obvious the occurrence of a factor of perhaps even more importance than methods of lumbering.

Most of our timbered areas, where man has not upset the natural balance, are well peopled with all sorts of animals from the lowest to among the highest. Not all this population is harmful to man and some is of decided benefit, and foresters would be the last to decry any denizen of the forest where the damage has been slight. While the rancher may be cursing the deer that nibble his fruit trees and spoil his vegetables, the forester may be bemoaning the diminishing number of deer in his domain. On the other hand, the forester joins the rest of the human race in attempting to exterminate the many rats and mice, not alone because of the food they spoil or the clothes they ruin, but also because they are agents which are helping to bring about the inevitable timber shortage.

Of late, we have come to realize that the biotic factor, especially as applied to the smaller rodents, is an important one. Mr. and Mrs. Rodent's fear of a hard winter leads them to store the Douglas fir seed in the heavy layer of duff and now foresters are using this characteristic as a recognized practice in forest management of the Pacific Northwest. Because the summers are long and hot and dry in parts of California, the pack rat finds his best drinks come from the inner bark of the pines, so he helps himself to the nearest young tree and, if the tree lives after a hard summer, it may furnish feed or drinks for other generations of pack rats. In the spruce country, because the tender spruce buds are rich in carbohydrates, young trees that show above the snow level are mowed down, so to speak, by the snowshoe rabbit, who esteems the spruce buds a rare delicacy. Even the forlorn cow or the wandering sheep will not starve before eating the young pine tree, and many acres of cut-over land in the southwest are devoid of young trees because of the good feed thus furnished.



After six years of excessive sheep grazing this young western yellow pine is all but a total loss. Overgrazing on many ranges has killed out the valuable forage plants and left the unpalatable feed to take complete possession. Pine trees are better than poor browse.

But we must not be too severe, for there are times when our rodent neighbors are most valuable to us.

Occasionally man desires to gather considerable quantities of seed of these forest trees for his forestation work. To pick up the seed one at a time would require the patience of Job, so man often "collects the rent" from his free tenants by breaking into the apartments and carrying off all the edibles the pantry affords, if he can. Particularly in the west, the little pine squirrel is abundant and has the habit of making certain of food for a hard winter by storing the seed and cones of the forest trees. As high as 40 bushels of western white pine cones have been found in a single squirrel cache in Idaho! Spruce seeds are stored in little pits or depressions holding from only two to three cones to as high as sixty, and usually at the base of a tree, stump or log. Douglas fir cones are often found in a hollow strip or in a brush pile. White pine cones are commonly under large logs or between two parallel logs lying close together and in one instance, under water. Very rarely, indeed, are two kinds of cones mixed in the same cache. One thing about these caches that make them important is that the squirrel, unlike his forester friend, can tell the difference between good and bad

A Squirrel Cache of White Fir Cones

This cache yielded about five bushels of cones which were piled up in a small depression near an overhanging bank.

seed, and in cutting the cones from the trees always gets the largest cones and those with the plumpest seed. With a heavy laden seed tree to work on, a single squirrel will take every good cone, cutting them off the branch at the exceedingly high rate of one a second.

This little game of "he hide, you find" can be a most interesting one, as many of the seed collectors can testify, for it is one requiring mental alertness, not only to find what the squirrel has salted away, but to keep it after you have found it. On one seed-collecting job the cone pickers were ahead of the transportation system and had left several sacks of seed lying along the roadside. As the pickers are paid on a collection basis, they had a personal interest in those sacks of cones, but so had the squirrels. Two Frenchmen, the best in the camp, quit, and one told why: "Zee little teef, heem; I swipe me heem one sack, and heem swipe me two sacks."

Then, too, in the early spring one can go through the forest or brush field and find little groups of seedlings from 2 or 3 to as high as 150 in a single cluster just poking their heads through the ground. These are the little rodent caches planted perhaps by some chipmunk who may have departed this life during the winter when he failed to find his storehouse, or he may have not needed this particular little cache and so failed to return. Even in older stands we often see two or three trees and sometimes more in a group which look like sprouts around a single old root, but which are quite apt to be the result of one of these little clusters. In one brush field examined this last spring, 60 per cent. of the seedling western yellow and sugar pines found could be traced to rodent activity, and most of these were at considerable distance from the nearest living trees. On another area, larger than the first one, 37 per cent. of the seedling trees on a sample tenth of an acre were the result of rodent caches, and it is safe to say that these and similar areas have even a greater percentage planted by the rodents, though we can not yet accept the hypothesis that all our forests owe their origin to friendly chipmunks or squirrels.

The harmful work of the animals does not stop with the seeding operation; it continues into the small seedling stage. Birds, of course, like the tender tips of the seedlings as they are pushed out of the ground, and perhaps it is as much a delicacy to them as asparagus is to us. Mice, too, are not entirely unappreciative of this form of vegetation, though perhaps they do not care so much for the trees at this time because usually there is other tender growth available, and often, too, at this time the mice and other relatives are still hibernating.

As the seedling gets up a few inches and begins to make a noticeable growth, he calls to his attention the rabbits and some of the

On many areas of the West, the presence of the chipmunk has been responsible for the lack of success in seed sowing operations where forestation has been attempted without planting. The chipmunk hunts up every loose seed that is overlooked by the other rodents. At times he is a beneficial forest resident for he often plants the seeds and forgets where he put them.

other relatives of the mice. Tender buds, especially in seasons when everything else is dry and hard, have considerable water and nothing suits some of these folk better than a drink of pine juice *a-la-bud*, "cool and refreshing." In the winter when food is hard to get and the seedling's head sticks above the snow cover, the fresh tender green of the conifer can not be mistaken, and another year's growth is gone, or the bark, both succulent and nourishing, may be transformed into hops, and the rabbit, rat or whatnot goes off to find another one.

In many places the forester would like to establish a tree cover, and the only way open to him is to plant small trees, for merely putting seeds out is a delightful way of feeding the poor. But although the same animals that like the seeds may not take the tender nursery tree, others will, and many a forester has cursed long and bitterly upon reexamining a plantation to find that every tree had been taken by parties unknown, and that even the small plant stakes marking the trees have been removed wholesale and utilized in the making of pack rat nests. Burrowing creatures like the digger squirrel have buried the young trees with the dirt excavated from their burrows, gophers have found the roots to their liking, and moles even have drawn imprecations down upon themselves because they enjoy traversing the fresh dirt where the trees were planted, leaving the roots of the tree suspended in air.

Eventually under natural conditions the forest somehow or other gets established and grows, but man in his desire to utilize everything brings in a few thousand sheep and cattle more than he should. After eating all the more palatable feed and exterminating it, the livestock with one accord turn to the young forest for the next course and soon eliminate the possibility there is to make a forest again of the area. After making his peace with the sheep and cattle men, the forester heaves a sigh of relief, but while his back is turned the porcupine has climbed into the young trees in the polewood stage, and, many feet from the ground, proceeds to strip off the bark, causing the trees to take upon themselves all manner of queer shapes, if they do not die from the repeated attacks. Even the mature trees suffer from the depredations of the porcupines, and the prevalence of "spike-top" trees throughout the southwest is a monument to the porcupines.

There is, then, a constant strain upon the forester, and as he reads in his SCIENTIFIC MONTHLY about the many queer and powerful animals his primitive fathers had to contend with, he is thankful that they are not creatures of the present day that he would have to contend with. He yawns and goes to bed with the assurance that some fearful and wonderful monster will not start on a rampage and proceed to devastate whole acres of forest, pulling it up by the roots or pushing it over as it walks playfully through the forest. But even before he drops to sleep he realizes with a start that such a creature does exist. Woe indeed was that day when man developed his timber-harvesting machinery, that Frankenstein animal which so often spreads destruction and scatters fire where'er it treads, the "donkey" engine.

The biotic factor is truly an important one!

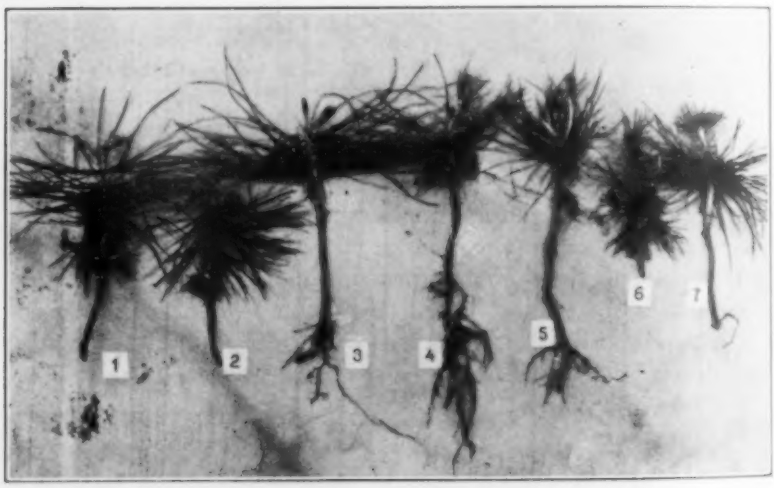
Nature, because she has so many children to feed, must provide for them with a lavish hand, and, because she must provide both for food and for the perpetuation of the species, her plant life must furnish much more seed than would otherwise be required to maintain it. In the forest she is perhaps just as generous as in the field or in the prairie, for the forest produces many thousand seeds per acre. Bates, in Colorado, found that a stand of spruce produced in one year over 41 pounds of seed or a total of 2,757,638 viable seeds, while a stand of Douglas fir produced per acre 11 pounds of seed or nearly 330,000 viable seeds. Yes, Nature sows with a lavish hand.

From the many thousand seeds produced per acre in every forest stand at intervals up to ten years, only two or three hundred trees per acre result and live to be a century or two old. Assuming, then, that in the virgin forest only 200 seeds are needed every two

centuries to take the place of the old stand, nature's lavishness is all too apparent. When man enters the stand as nature has produced it, conditions are changed markedly, for in place of waiting the two centuries to harvest a crop, he harvests his forest crop at around 50 years, and needs therefore four times as many seeds as did nature. In fact, he needs more as he raises, to be taken when 50 years old, perhaps three trees where one stood heretofore. He goes still farther, for he makes his ground produce all it can up to that period: at 15 years by thinning he takes out a crop of Christmas trees; at 25 years he takes out fence posts; he removes pulpwood at 35; he cuts poles at 40 years. Man's needs, therefore, can not be satisfied without a stand at the beginning of the new forest of between one and three thousand trees per acre, or about 8,000 trees every two centuries.

All this upset to nature's balance is reflected in the forester's actions. He can not now leave simply two or three seed trees per acre where seed trees are needed, he must leave three times as many, for the squirrels will take the pine cones before they begin to open, the seed that is left to be disseminated is eagerly awaited by the foragers who do not get off the ground, and if any seed escapes, it is because the rodents in that locality failed to smell or see it. So it is, unconsciously perhaps, that the forester leaves trees that he might otherwise have taken if some of his rodent enemies were out of the way.

Needing only about 2,000 good seeds per acre every 50 years



Trees from a plantation of Jeffrey pine in southern California. Plants 2 and 6 from a pack rat nest; roots on 1, 3, 7, cut off by gophers; roots on 5 taken by digger squirrels; roots on left of 4 killed by exposure to air in a mole tunnel.

there should be seed enough for both man and the smaller rodents and birds that formerly got it all, but man, unfortunately, wants his seed at a definite time and if anything interferes with their abundant and widespread sowing, that thing immediately becomes a factor detrimental to man's welfare and must be put aside. Unfortunately, man and other animal life do not speak the same language and, unlike other landlords, he can not give notice on the tenants and boarders of his apartment house to vacate on the first of May.

However, man must do something, and, as usual, he does the wrong thing. As a matter of policy he should require only the undesirable tenants to get out—the mice, the rats, the chipmunks, the squirrels and all their kith and kin—but instead, what does he do? First, he invites the lumberjack in and he makes no protest to the "man with the ax" when he destroys all the many enemies of the smaller rodents that he comes across in the day's work. A snake is a snake whether it be rattler or garter; a coyote may have rabies, besides he keeps the man awake nights with his music; a wild cat may attack him at any moment, a skunk is anathema on general principles; a fox has a good pelt; hawks and owls kill chickens; and so on. To the lumberjack a tree is to be cut, an animal is to be killed—values, size, location, quantity—all are alike to him, and the forester too often considers only trees and overlooks the biotic factor.

Second, the forester encourages the trapper and "points with pride" to his annual report in which 30 per cent. more pelts were taken this year over last, regardless of the fact that many of those pelts belonged to his friends, many of whom he should mourn.

Third, the forester tries to make the forest "sanitary" by putting into effect sanitation measures which will result in a "clean" stand at the next cut. Old logs, which harbor small rodents, are burned, but many of these old logs also harbor the rodent's enemies. Hollow trees and rotten ones which might infect the new forest with the most unspeakable (except by pathologists) fungi are destroyed, though the owl living there never caught the disease. Snags and old dead trees are cut lest they be struck by lightning or hold a fire for a long time, while the poor woodpecker who has done nothing but help to keep the destructive bark beetle in check has nothing left to drum upon but the tin roof on the ranger's garage.

Fourth, the forester encourages, aids and abets the tired business man, the city man, the "recreationist" of whom we have heard much of late, to come to our forests and renew his youth in the timber with the help of the family and flivver, dog and gun. He is

invited to come, is assisted in having a good time, and promptly retaliates by killing the forester's friends and—we must be truthful—every once so often while his wife huddles in a corner of her tent and shivers he does kill one of the forester's enemies as well.

As a means of correcting the abuses which have developed and which are upsetting the natural balance in our forest, there are several things that can be done to bring about more stable conditions. The first of these is a campaign of education among the forest users as to the necessity of maintaining our wild life as far as possible in its present status. All animals should be protected from the promiscuous killing which is now going on, though. We recognize that the destruction of dangerous snakes or of destructive animals, such as the mountain lion, may be very desirable, but the killing for killing's sake of many of our harmless snakes and beneficial mammals is greatly to be deplored. The general public itself very seldom stops to think of the consequences set up by its misuse of the forest, while the majority of the lumberjacks have absolutely no conception of the rôle that biotic factor plays in the development and maintenance of our forest stands.

Whether or not we should encourage trapping in our forests throughout the United States is another matter. Trapping has been responsible for the destruction of many of our fur-bearing animals almost to the point of extinction and this destruction is keeping on at an ever-increasing rate due to the demands of civilization for furs of all kinds to adorn the so-called weaker sex.

A third thing that can be done to maintain our status quo with relation to our smaller animal friends is to set aside areas here and there throughout our forested regions to remain in a state of more or less natural preservation which will serve as homes for those animals that normally are rendered homeless by lumbering and forest sanitation. The presence of snags, old logs and débris of all kinds in these areas is very conducive to maintaining our forest friends through furnishing them suitable hiding places and protection so as to permit their increase and once again make themselves felt as a beneficial influence in our forestry problem.

We are depending upon natural reproduction more and more to restock our denuded areas and if we permit the rodents to gain the ascendency on these areas through the destruction of their natural enemies, we can look for an increase in the cost due to planting that could be avoided to some extent by the protection we may give to the larger mammals. The whole question of biology comes up repeatedly in our forest practices, and nowhere is it so important as in the regeneration of our forest stands.

THE PROGRESS OF SCIENCE

By Dr. EDWIN E. SLOSSON
SCIENCE SERVICE, WASHINGTON

TWO KINDS OF CONSERVATION

CONSERVATION is one of those deceptive words that have a double meaning. It is doubly dangerous because its meaning in one case is quite the opposite of its meaning in another case. For instance, in the conservation of our natural resources, a politician with an agate-bearing tongue may say: "I am in favor of the conservation of our petroleum and water power."

Very good. But he and his audience do not always realize that contrary policies must be adopted in the two cases. The conservation of oil means not using it, for all the oil that is used is forever lost. The conservation of water power means using it, for all the water power that is not used is forever lost.

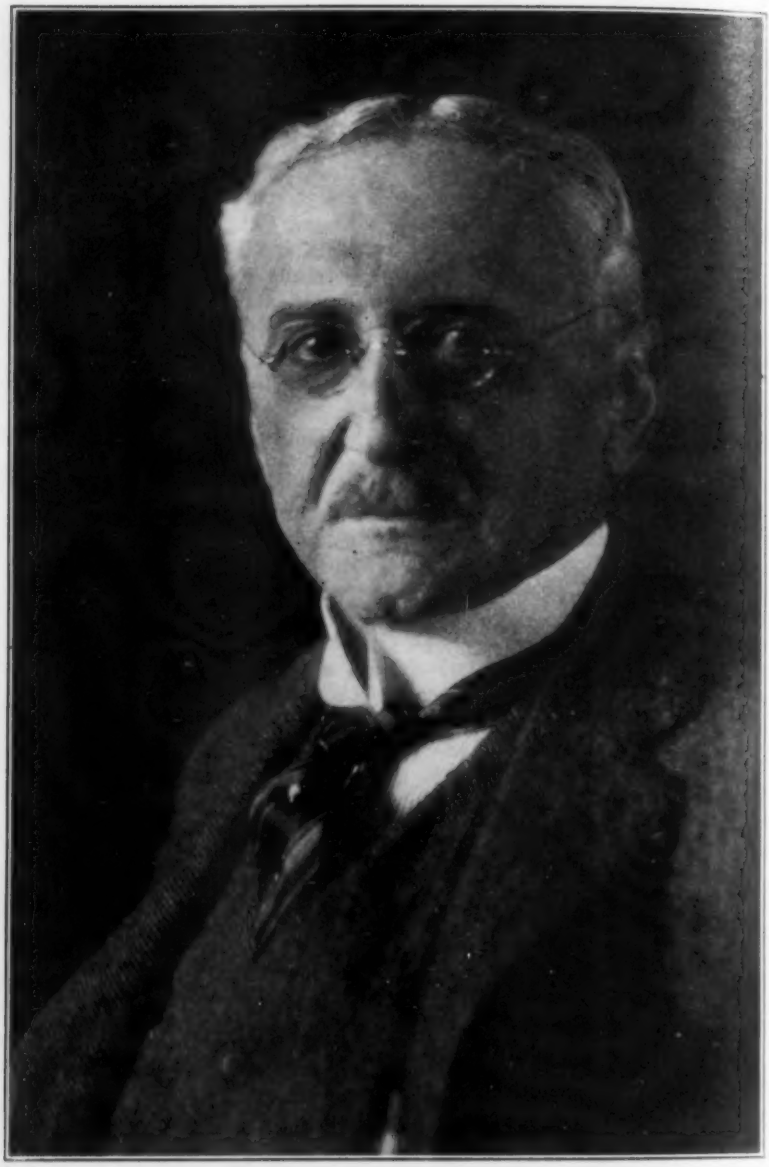
Oil and water do not mix. Both oil and water are limited and inadequate to our needs. But the oil supply is exhaustible while the water supply is inexhaustible. Day by day the sun pumps up water from the ocean and the winds carry it over to the mountains where it falls as rain and fills the streams.

But there is no reason to think that Providence will ever renew the supply of oil that we are so lavishly and wastefully using. Dividing the amount of petroleum left in the earth of our country, estimated at about nine billion barrels, by the amount we withdrew from deposit last year, 745,000,000 barrels, we get 12 as a quotient. That means in a dozen years or thereabouts we will run short of the gasoline and oil that we have been getting from petroleum and that we will have to seek other sources. What those sources will be we do not know but we may be sure that liquid fuel and lubricants will be dearer and more difficult to get in the future. We might get them from oil shale, it is true, but shale has to be mined and extracted while petroleum runs out as soon as its reservoir is tapped.

In some parts of our country we can still see the blazing beacons of natural gas burning all night from our pipes, but most of the communities which formerly have been favored by free use of gaseous fuel have had to fall back on coal.

And there is not enough coal to go around or to last long. Three continents, Africa, South America and Australia, have not enough coal to support an industrial civilization like that of modern Europe. But Europe can not keep up its present consumption of coal for many centuries. The United States and China seem to be the most favored nations in the matter of fossil fuel. They have enough coal to last several thousand years, but that is not forever and we hope it will be but a short chapter in the history of the human race.

Meantime we are wasting the greater part of our coal by inefficient combustion and by toting it back and forth across the country unnecessarily. The miner gets only one crop while the farmer gets a new crop every year. That is because the miner is using up the accumulated carbon of past ages while the farmer accumulates his carbon anew with the aid of each summer's sunshine. One is living on the capital of the world's



JACQUES LOEB

APRIL 7, 1859–FEBRUARY 12, 1924

Member of the Rockefeller Institute for Medical Research and head of its division of general physiology, in whose death the world loses one of its most original and distinguished biologists.

wealth; the other on its interest. The central power house of the solar system has been sending out its energy by radio without any perceptible diminution for some millions of years in the past and seems likely to last at least as long in the future. An impartial Providence has arranged it that the earth revolves as a spit before the fire so that every land receives in turn a share of the sun's rays. Furthermore, every land has been supplied with a supply of carbon and oxygen in exact proportion to its area, since these are free as air.

But only the plants possess the secret of economically separating carbon from oxygen and storing up the former as food and fuel for future use. And even the plants are not good at it although they had practiced the art of manufacturing carbohydrates for many millennia before man came on the scene. The green leaf wastes ninety-nine per cent. of the energy it receives from the sun. But on the one per cent. of the original solar energy that is recoverable on combustion of the combined carbon depends all the life of the world and all the power of the machinery of man except what little he gets from waterfalls and windmills. Water power we are beginning of late to utilize, but wind power we employ less than we used to when it propelled all the ships and ran many of the mills. We have more wind than we want in some places, yet we waste the most of it without a thought of conservation.

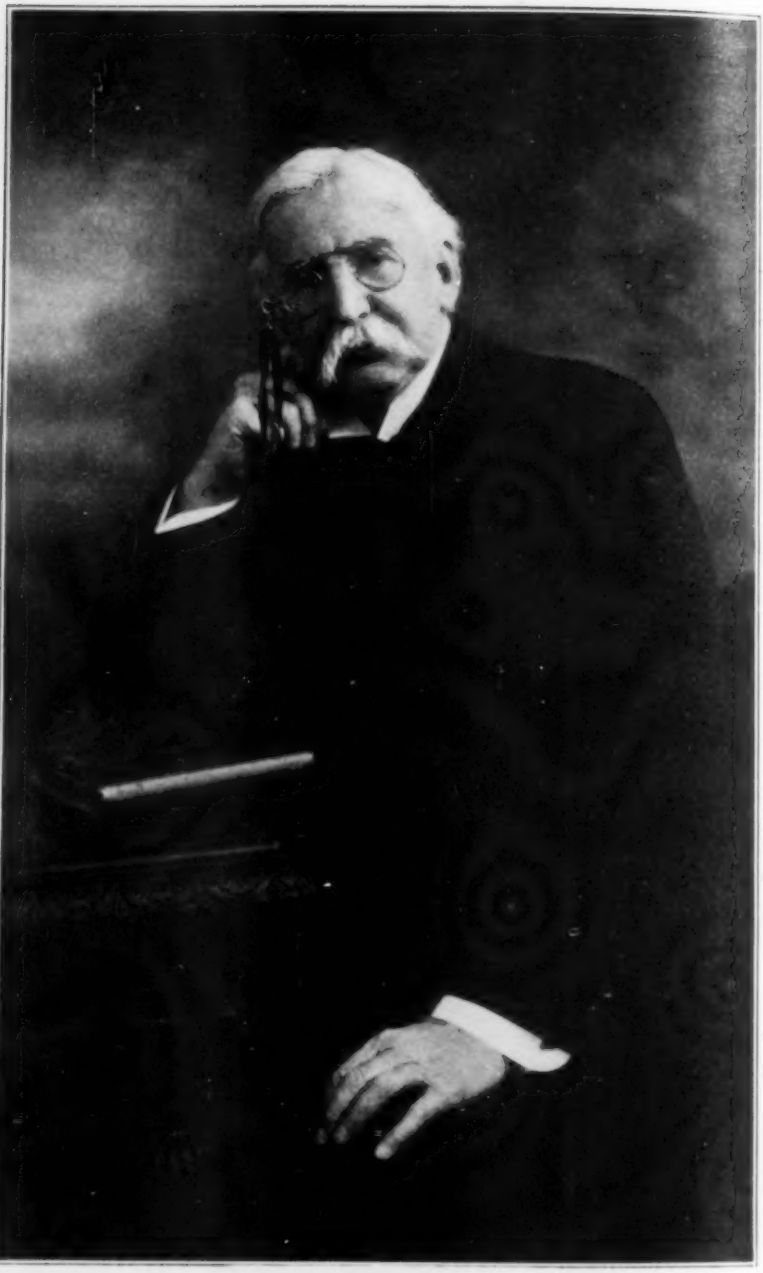
The best definition of this ambiguous word I ever saw is that of Acheson: "Conservation consists in the utilization of the inexhaustible for the preservation of the exhaustible." Coal, oil and gas are exhaustible. Water, wind and sunshine are inexhaustible.

CHEMICAL MESSENGERS

WHAT system of government prevails in this body of ours? Is it an autocracy, the one-man rule, such as prevailed in the primitive state and still survives in the army? Or is it a democracy, the equal power of all in politics, regardless of their qualifications, such as is now regarded as the ideal? Or is it an oligarchy, where the superior cells and organs manage the inferior?

Strange to say no system of human government has yet been devised that approaches the organization of the animal organism in character—or in success. The millions of cells, the hundreds of muscles, the dozens of organs, with their infinitely varied powers and functions, are kept in harmonious activity for the good of the whole by some secret system of mutual cooperation which man has not yet learned how to apply to his artificial organism, the state.

The conscious ego can not claim to be the dictator of the physiological realm which he calls his body. He is not even a Premier, but merely a Foreign Minister. He has a certain control over imports and exports, but the Department of the Interior is mostly beyond his jurisdiction. It is his business to keep the body out of fights with others that might result in a stab in the heart or a punch in the stomach, but he is not entrusted with such essential functions as keeping the heart pumping and the stomach digesting. For, important as the mind may think itself, it sleeps at its post for a third of the twenty-four hours and is liable to occasional fits of forgetfulness at any time. It is not the brain that mobilizes the white blood corpuscles whenever an army of microbes invades the body through a breach in the outer wall. Sight is not sharp enough to see a microbe and even if the brain suspected an invasion it would not know how to conscript the corpuscles and despatch them to the front.



DR. FREDERIC A. LUCAS

The distinguished zoologist and museum administrator, who at the age of seventy-two years became director emeritus of the American Museum of Natural History.

All these millions of living cells in brain or brawn or bone have to be kept supplied with food, water and air in amount depending on how they are working and how fast they are growing. The temperature of every part of the body has to be kept constant no matter whether the weather is cold or warm, and the ashes must not be allowed to accumulate in any cell.

Now one would think that such a marvellously complicated coordination of interdependent activities would require a strict system of bureaucratic centralized government. But on the contrary the central government, if there is such, has little or nothing to say about most of the physiological processes. The orders to an organ come from below rather than above. For instance, if an overworked muscle needs more oxygen it does not petition headquarters, but sends orders direct to the heart and lungs to speed up the pumping. If a gang of structural bone workers want more lime or phosphate they do not bother the boss about it but dispatch a message straight to the supply department to import some.

How these multifarious messages could be carried was long a mystery but is now being solved. There are two ways of intercommunication in the body just as there are in the outside world, telegraph and mail. In a telegraphed message nothing travels except the electrical impulse, but in the postal service a material message, the letter, is transmitted. Inside the body signals may be sent by the nerves which play the part of telegraph wires, but it has recently been discovered that there is another and more general system of intercommunication by means of chemical substances sent around through the blood like letters. Professor E. H. Starling, of London, pointed out the importance of these eighteen years ago and named them "hormones" which is Greek for "messengers" and since then many of them have been discovered and some of them manufactured.

The two systems of transmitting orders supplement each other like telegraph and mail. For instance, a man sits down at a dinner table. The eye signals by way of the nerves, "I see food," and a minute later comes confirmation from the nose, "I smell it." At once the saliva begins to pour into the mouth and the gastric juice into the stomach to prepare for the first stages of digestion.

Some time later when the stomach has finished its work three other digestive fluids have to be in readiness. These are secreted by three separate organs, the pancreas, the liver and the intestinal glands, and all these have to be notified to get busy as soon as the first food passes out of the stomach.

In this case the message is conveyed by a hormone called "secretin" which within two minutes after it has been sent into the blood stream sets the three organs to preparing their particular digestive juices.

If we get angry or scared the body has to be put into a state of preparedness for fight or flight, whichever the high authority decides upon. But either will require an extra supply of energy, so the suprarenal glands, without waiting for special orders from headquarters, send a chemical messenger to the heart to pump harder and to the liver to release more sugar into the blood so that no muscle shall be short of fuel in this emergency.

How the sugar is handled depends on another hormone known as "insulin," which has lately been prepared in a form that may be used by diabetics whose pancreas does not work well.

Still more recently comes the announcement of the extraction of a pure

and extremely powerful form of "pituitrin," the secretion of the insignificant pituitary body, that controls the kidneys and capillaries.

The chemist is now able to make "thyroxin," which is secreted by the thyroid gland, and a minute daily dose of this may, as Dr. Starling says, effect "the conversion of a stunted, pot-bellied slavering cretin into a pretty, attractive child."

It is these chemical messengers which in infinitesimal amounts determine whether we shall be tall or short, dark or fair, handsome or ugly, active or sluggish, alert or stupid, cheerful or melancholy, and it is the aim of the chemist to learn how to make them or perhaps similar substances of even greater potency so that he can acquire absolute control over the workings of the human body.

THE PREDICTION OF EARTHQUAKES

Dr. Thomas A. Jaggar, Jr., director of the Hawaiian Volcano Observatory, which is connected with the Weather Bureau of the United States Department of Agriculture, is at present in Washington on an official visit. Dr. Jaggar made a trip to Japan this fall for the purpose of conferring with scientists of that country in regard to the disaster of last August due to earthquake and fire, and also to make observations which might add to the scientific understanding of the phenomena attending such calamities. While here he will prepare a comprehensive report on the subject.

"At the present time there is no known means of predicting an earthquake or a volcanic eruption," stated Dr. Jaggar, when interviewed. "It is believed, nevertheless, that with continued study of this subject we may obtain data which will enable us to send out warnings in time to save lives and, to some extent, protect property. Flood warnings on the great river systems annually save hundreds of human beings and thousands of dollars worth of movable possessions. Increased information about these volcanic and seismic disasters which have occurred should furnish a better understanding of the precautions in building, and in community practices that might be taken by those living in regions subject to such disturbances. We know now, for example, that the important consideration in regard to buildings is not so much what kind of building as how well constructed it is. Many of the wooden Japanese buildings withstood the earthquake perfectly, whereas masonry in numerous places went down with terrible consequences. Fire, however, destroyed hundreds of wooden structures that resisted the earthquake."

The earthquake had very powerful effects on the contour of the Japanese coast and the bays adjacent to it. Landslides occurred which affected the steep shores, and the bottom of the sea was greatly changed. Many other towns in addition to Yokohama and Tokio were damaged, and many other fires were produced. There were a noticeable number of resistant buildings, especially those recently built, but the very old structures, with poor foundations, all went down. Differences in the kind of ground on which buildings stood affected their resistance to shock.

Owing to its high cost, very little earthquake insurance is ever carried to offset possible loss, in spite of the known risk in some regions. There is great need of accurate data on which to base earthquake insurance rates. Further investigation of the subject ought to make it possible to adjust the cost so as to bring this insurance within reach of those who need it.